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Soil Temperature and Sewage Sludge Effects on Plant and Soil Properties

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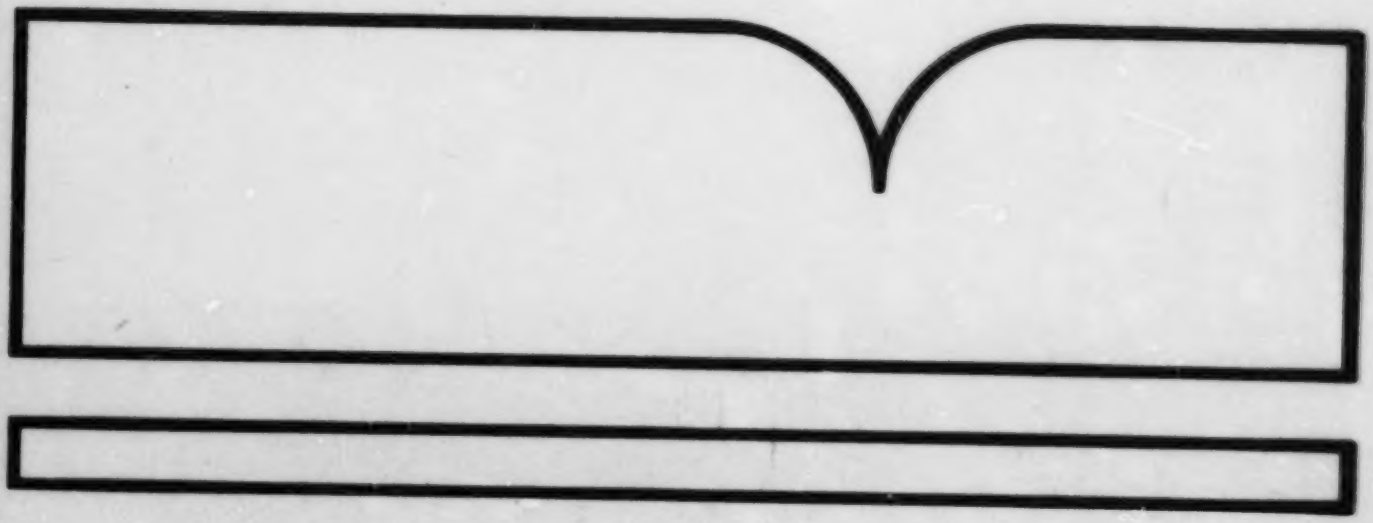

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SOIL TEMPERATURE AND SEWAGE SLUDGE EFFECTS ON PLANT AND SOIL PROPERTIES

by

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16. ABSTRACT

A field experiment was conducted to determine the influence of soil temperature and sewage sludge on growth and composition of corn (Zea mays L.). Changes in soil organic matter, extractable metals, pH, bulb density, aggregation, fecal coliform, and fecal streptococcus were determined. Soil temperatures studied were 16, 27, 35, and 22 °C (ambient). Sludge was applied at rates of 0, 56, and 112 metric tons per hectare.

Corn yields and growth were reduced by 16 °C soil temperature, and increased by heating the soil to 35 °C in 1976, but the warmer soil did not significantly increase yields in 1975.

The effects of soil temperature on heavy metal concentrations in plants varied according to year, metal, and plant part. Zinc concentrations generally increased with increased soil temperature. Sludge increased concentrations of Zn, Cu, Ni, and Cd in corn, radishes, legume and small grain tissues. Cd increased significantly in corn seedlings with soil temperature increase, but not in stover.

The highest rate of fecal coliform and fecal streptococcus addition and the longest survival times in soil were on plots receiving the highest sludge application. Survival time varied directly with soil temperature.

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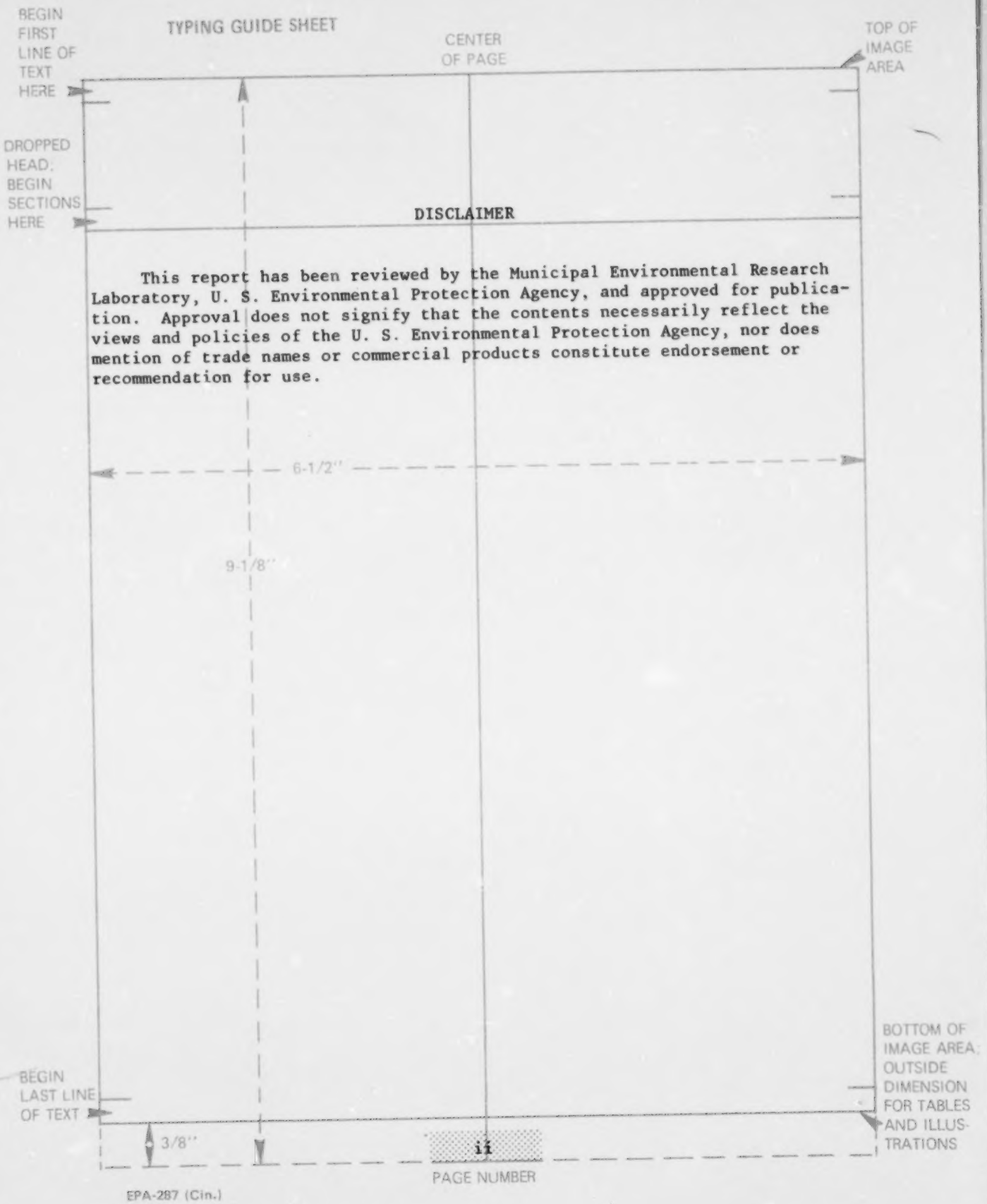
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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

Extrapolation of data from research projects in areas of known soil and climatic characteristics to areas with different environmental conditions allows prudent use of sludge on land with a minimum of research. This report contains information about the effects of soil temperature on the fate and effects of sludge constituents that will enhance the use of sludge on land.

Francis T. Mayo, Director
Municipal Environmental Research
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ABSTRACT

A field experiment was conducted for two years to determine the influence of soil temperature (16, 27, 35°C and ambient (22°C)) and sewage sludge application (0, 56, and 112 metric tons/ha) on the growth and composition of corn (Zea mays L.); and the organic matter, extractable metals, pH, bulk density, aggregation, fecal coliform, and fecal streptococcus levels in the soil. Radish (Raphanus sativus L.), small grains, and legumes were also grown.

Corn growth rates, grain and stover yields were significantly reduced by 16°C soil temperatures in 1975 and 1976. In 1976, stover and grain yields were significantly increased by soil heating to 35°C, but in 1975 effects were generally not significant. Sewage sludge application had no effect on stover yields in 1975, but did significantly increase grain yields of 16°C temperature plots. In 1976, grain and stover yields from check plots were lower than sludge amended plots at all soil temperatures.

Nitrogen, P, and K levels in corn ear leaves were higher at 35 than 16°C in both years, but Ca was lower. Higher ear leaf N, P, Ca, and Mg concentrations occurred in both 1975 and 1976 due to 112 metric ton/ha sludge than check plots.

Concentrations of Zn, Cu, Ni, and Cd were increased in corn, radishes, legume and small grain tissue by sludge treatments. Corn seedling Zn and Cu concentrations exceeded that in ear leaves, stover and grain, but were similar to that found in legumes. Lowest metal concentrations were found in the corn grain. Increasing soil temperature did not consistently affect Cu, Ni, Cd, or Pb concentrations in corn tissue. Zinc concentrations in corn tissue generally increased as soil temperature rose, but exceptions did exist. Increasing soil temperatures resulted in higher radish metal concentrations in 1975, but effects were less pronounced in 1976. No residual soil temperature effects on metal concentrations in legumes or small grains occurred.

Sewage sludge application resulted in significant increases in soil organic matter, pH, and DTPA extractable Zn, Cu, Cd, and Ni. Soil heating to 35°C significantly reduced soil pH compared to 16°C and ambient (22°C) temperatures by the conclusion of the experiment. Soil temperature had no effect on soil organic matter or DTPA extractable metals on each of eight sampling times, but when averaged for the duration of the experiment, lower organic matter and Zn and Cu levels were observed for 112 metric ton sludge plots subjected to 35°C soil temperatures compared to 16°C. Bulk density and aggregation were not affected by soil temperature. A downward movement of Zn and Cu was observed with greater movement found at lower soil temperatures.

A longer fecal coliform and fecal streptococcus survival was noted at the lowest soil temperature (16°C) and the shortest survival was found at the

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highest temperature (35°C). Sludge addition resulted in significant increases in fecal coliform and fecal streptococcus numbers in the soil. The addition of a high rate of sludge resulted in the longest survival time for both indicator bacteria at the highest temperature studied.

This report was submitted in fulfillment of cooperative agreement EPA-IGA-D-X0376 by U.S. Department of Agriculture, SEA, AR, Beltsville, Md., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period May 1, 1975 to September 30, 1979.

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SECTION 1

INTRODUCTION

Large amounts of digested sewage sludge are produced annually in North America by municipalities in diverse climatic conditions. Sewage sludge is the semisolid colloidal residual derived from the treatment of sewage. It is produced by physical, biological, and chemical processes. Disposal of sewage sludge safely and economically is becoming more difficult, and efforts have been made to utilize it as a fertilizer on agricultural land and for the reclamation of waste lands.

Sewage sludges contain high amounts of essential plant nutrients N, P, Zn, and Cu relative to crop residue or animal manure. Sludge organic matter is desirable for improving soil chemical and physical properties. Due to the recent energy shortage, fertilizer costs are increasing and agronomists are looking to alternate sources of plant nutrients. The application of sewage sludge on agricultural land would solve many of the problems faced by cities and farmers. Sewage sludge sometimes contains excessive amounts of metals, especially Zn, Cu, Cd, Ni, and Pb, which can be phytotoxic and pose a threat to the human food chain. The fate of pathogenic organisms in the sludge is also a concern. Proper soil and crop management are essential for safe disposal and usage of sewage sludge.

Availability to plants of metals and nutrients in sewage sludge is closely related to the organic fraction. Soil temperature is important in the degradation of organic matter and usage of sewage sludge under conditions which stimulate degradation should be carefully evaluated. In addition to influencing metal availability, soil temperature affects plant uptake and translocation of heavy metals.

A field study evaluated the relationship between soil temperature and sewage sludge using the soil temperature control facilities at the Agronomy Plant Research Farm, Fairland, Maryland. Four soil temperature regimes were maintained. Data from these experiments should help provide guidelines for safe sludge application to agricultural land under different climatic conditions.

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SECTION 2

CONCLUSIONS

Soil temperature had a pronounced effect on corn growth. Below ambient soil temperatures (16°C) significantly reduced yields of grain and stover. This was expected because corn is a warm season plant which makes optimum growth at temperatures of 24 to 30°C. The largest increases in yields occurred as soil temperature increased from 16°C to ambient (22°C). Above ambient soil temperatures produced no significant grain or stover yield changes in 1975, but in 1976 an increase in yields was noted. The 1976 response may be attributed to an increase in plant yield potential by soil heating during an abnormally cool spring. In both years plants were taller, had more leaves and matured earlier at 35°C than at 16°C. Highest quality stover was produced at 16°C, possibly due to reduced lignin biosynthesis and stem elongation.

Sewage sludge application had little effect on grain or stover yields at most soil temperatures in 1975, but grain yields were significantly increased on plots subjected to a 16°C soil temperature. In 1976, check plots had significantly lower grain yields at all soil temperatures than those to which sludge was applied. Stover yields were significantly lower for check plots than plots amended with 112 ton/ha sludge at all temperatures except 16°C where no significant effect was observed.

Sewage sludge application increased N, P, Mg, and Ca concentrations in corn ear leaves in both years of the experiment. Potassium levels were not increased. Nutrients added in the sludge increased concentrations in the ear leaves and may be responsible for higher yields from sludge amended plots in 1976. Higher concentrations of N, P, and K were found in corn ear leaves from 35°C than 16°C plots in both years. Calcium concentrations were consistently higher in ear leaves from 16°C plots.

Sewage sludge application increased the Zn, Cu, Cd, and Ni levels in corn plants. Due to the high concentration of Zn and Cu in the sludge, these elements were present to the largest extent in aerial portions of the plant. Zinc and Cd appeared to be translocated more than the other heavy metals evaluated. Lead levels in plants were not increased due to sewage sludge application.

The effects of soil temperature on heavy metal concentrations in plants varied considerably according to year, metals, and plant materials. Soil temperature had no significant effect on Ni and Pb concentrations in stover, grain, ear leaves, or seedlings. Zinc levels in ear leaves and seedlings from plants grown on sludge amended plots were significantly higher for both years at a soil temperature of 35°C than at 16°C. Soil temperature effects

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on stover Zn concentrations were variable and possibly masked due to dry matter effects. Lower Cu concentrations were observed in ear leaves, stover and seedlings at 16°C than at other soil temperatures. This was not significant all years and for all sludge rates. Seedling Cd concentrations were significantly higher each year at 35 than at 16°C. Cadmium levels in ear leaves and stover were not significantly affected by soil temperature.

Sewage sludge application resulted in significant increases in soil organic matter, pH, and DTPA and double acid extractable metals. Organic matter levels in sludge amended plots decreased significantly during the 68 weeks of the experiment. Available Zn and Cu concentrations as measured by DTPA extraction increased from the start to the end of the experiment. No consistent changes occurred in Ni and Cd concentrations. Soil bulk density decreased and soil aggregation increased as a result of sewage sludge application.

Effects of soil temperature on soil organic matter and DTPA extractable metal levels were small and non-significant within soil samplings taken during the experimental period. At all sludge rates, 35 and 27°C soil temperatures resulted in a significant reduction in soil pH by the conclusion of the experiment. Ambient and 16°C soil pH values were not significantly different. Soil temperature had no effect on bulk density or aggregation.

Increases in sewage sludge application rates resulted in significant increases in the heavy metal concentrations of both radishes and forages. Radish tops had higher metal concentrations than roots. The effects of temperature and sludge treatment were more apparent on radishes than corn. Legumes grown during winter months, when soil temperature was not regulated, had higher metal concentrations than small grains, but the legume or small grain metal levels were not significantly affected by residual soil temperatures.

Higher levels of heavy metals found in plants at 35°C versus 16°C soil temperatures appear to be a function of temperature stimulation of plant uptake and translocation processes, since heavy metal availability to plants as measured by DTPA extraction was only slightly affected by soil heating. Also, no residual temperature effect on metal content of legumes or grasses was observed.

Fecal coliform and fecal streptococcus survived longer at the lowest temperature (16°C) and the shortest survival was found at the highest temperature (35°C). The addition of sludge at a high rate resulted in the longest survival time for both of the indicator bacteria at the highest temperature studied. These data indicate that sludge addition at high rates when soil temperatures are low would result in the greatest pathogen survival, and low sludge addition when soil temperatures are high would result in the lowest rate of pathogen survival.

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SECTION 3

RECOMMENDATIONS

The increases in corn yields as a result of sewage sludge application and soil heating indicate their potential for use in agriculture. The improvement in yields the year after application shows the residual benefits of sewage sludge application. Variations in response between 1975 and 1976 due to soil heating to above ambient temperatures indicate that environmental conditions must be considered in evaluating soil heating.

Soil heating to above ambient temperatures throughout the growing season cannot be recommended for field crops such as corn. It may be profitable for the growth of horticultural crops with a high value per unit of production. Growth of a corn variety requiring a longer growing season would result in increased dry matter production due to the temperature effect in decreasing days to maturity, but the yield increase might be economically insignificant. Additional research is needed on the effects of soil temperatures during the seedling stage on the yield potential of corn.

High temperatures increase the risks involved with the use of sewage sludge as a plant growth media. Due to the increased uptake of metal by plants at higher soil temperatures, it is not recommended that sewage sludge be used in combination with soil heating in greenhouses, or waste heat disposal projects. The disposal of high metal sewage sludges on land subjected to climates with high temperatures may also be a hazard.

Selection of plants which exclude metals while making maximum use of the desirable properties of the sewage sludge should be considered. Compared to radishes and legumes, corn was a low accumulator of metals, yet as a row crop, benefited from the organic matter and nutrients added via the sludge. Growing metal accumulators, such as radishes, on sludge amended soil may produce a crop that is hazardous to human health.

Additional research must be conducted on the influence of organic matter in heavy metal availability. Management principles such as soil heating could be better understood if the soil chemistry of metals and organic matter-metal interactions were explained.

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SECTION 4

EXPERIMENTAL PROCEDURES AND MATERIALS

A field study evaluating soil temperature and sewage sludge application effects on crop growth was conducted at the University of Maryland Plant Research Farm, Maryland. Field research was initiated in the spring of 1975 and concluded in the fall of 1976.

FIELD OPERATIONS

The experimental design was a split-plot with three replications. Target soil temperature regimes (whole plots) of ambient (mean value = 22°C), 16, 27, and 35°C were maintained in 4.5 x 1.8-m plots, of which 1.5 x 1.8-m (sub-plots) received sludge rates of 0, 56, and 112 metric tons/ha. All plot areas were enclosed by 5-cm wood framing to prevent sludge movement and contamination. Following the initial sludge application on 15 May, 1975, no additional sludge was applied to plots during the experiment.

Soil temperatures were maintained by circulating water-ethylene glycol solution through tubing approximately 20 cm beneath the plot surface. Stainless steel tubing (18 cm between tubes) was used for circulation of the coolant. The pumping and temperature regulation equipment used to establish the whole plot treatments was designed by MacLeod and Decker (1968). Details of the equipment are given in Appendix A. Soil temperature regimes were maintained from May to October in 1975 and 1976. Temperature was not controlled from October to May (winter of 1975-1976).

Sludge was obtained from the Back River Sewage Treatment Plant which treats its waste water by primary sedimentation, followed by secondary activated treatment with part of the flow being treated by a trickling filter. Mixed raw sludge is anaerobically digested in high-rate, mixed, heated digesters. Fluid digested sludge was elutriated, treated with ferric chloride, and vacuum filtered to 20% solids. This filter cake was mixed with an air-dry Sassafras sandy loam (Typic Hapludults-fine, loamy, siliceous, mesic) in proportions necessary to obtain the desired sludge amendment rates. The same amount of soil was added to each sub-plot so that sludge-soil depth above the temperature grid increased with sludge rate. The composition of the sludge and soil-sludge properties each year of the experiment are shown in Tables 1 and 2. Check plots (zero sludge) were fertilized with 180 kg N/ha (NH_4NO_3) prior to planting in 1975 and 1976. All plots were fertilized with 112 kg K/ha (KCl) in 1976.

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TABLE 1. COMPOSITION OF SEWAGE SLUDGE USED IN FIELD EXPERIMENT*

Element	Concentration
N	3.0%
P	2.0%
K	0.1%
Ca	0.8%
Mg	1.1%
Zn	4400 µg/g
Cu	2200 µg/g
Pb	140 µg/g
Ni	170 µg/g
Cd	16 µg/g

* Analysis is expressed on a dry weight basis.

TABLE 2. ANALYSIS OF SOIL AND SOIL-SLUDGE MIXTURES ON 20 MAY, 1975 AND 16 JULY, 1976

Year	Sludge treatment	pH	Cation exchange capacity	Organic matter	Extractable		
					P	K	Mg
	Mt/ha		meq./100 g	%	kg/ha		
1975	0	5.5	5.62	1.30	184	166	171
	56	6.0	9.41	2.29	441	185	302
	112	6.2	11.06	3.20	537	174	321
1976	0	5.3	---	1.29	81	118	95
	56	5.7	---	2.11	295	121	161
	112	5.7	---	2.84	422	130	186

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Soil temperature from one replicate and air temperatures were recorded continuously at two-hour intervals throughout the experimental periods. Copper-constantan thermocouples were embedded into each plot at a 5-cm depth and two thermocouples were placed 30 and 150 cm above the soil near the center of the plots. Thermocouples were also placed on stainless steel tubing entering each plot to monitor the temperature of the circulating liquid. Soil and 15-cm air temperatures for 1975 and 1976 are shown in Appendix B. Average 5-cm soil and air temperatures at 30 and 150 cm are shown in Table 3.

TABLE 3. AVERAGE SOIL (5-CM DEPTH) AND AIR TEMPERATURES FOR 1975 AND 1976 GROWING SEASONS

	Target soil temperatures (°C)				Air temperature	
Year	16	Ambient	27	35	30 cm	50 cm
	- - - - - - - - - - - - - - - - - - °C - - - - - - - - - - - - - - - - - -					
1975	16.8	22.2	25.0	31.7	22.3	22.2
1976	16.9	22.0	26.0	32.7	22.4	22.4

After seedbed preparation, field corn (Zea mays L.) 'Dekalb XL-43' (approximate growing season length of 110 days) was planted in each plot and in surrounding borders on 28 May, 1975. The corn seed was planted perpendicular to the heat source at a 3.8-cm depth in rows 51 cm apart. Within the row, seeds were spaced 5.1 cm apart. Radishes (Raphanus sativus L.) 'Scarlet Globe' were planted in rows between the corn and thinned after germination until a spacing of one plant per 2.5 cm was obtained. The temperature regulation system was started on 29 May, 1975. Although it would have been preferable to apply temperature treatments prior to planting, equipment failure caused heat application to start after planting.

Following planting, approximately 4 cm of barley straw was placed over the entire plot area to conserve soil moisture and reduce diurnal soil temperature fluctuations. Polyvinyl chloride tubing equipped with horizontal spray nozzles was placed over the straw surface for irrigation. Tensiometers were installed in the check sub-plots of each whole temperature plot to obtain an approximate measure of soil moisture status. Due to differences in applied temperatures, water requirements varied; therefore, plots of each temperature regime were irrigated separately as needed to maintain "uniform" soil moisture (Table 4). Average monthly rainfall data for the 1975 and 1976 growing seasons are shown in Table 5.

Corn seedlings were harvested at the 8 to 9-leaf stage. Plants were cut at the soil surface using stainless steel instruments. Seedlings were measured for height with leaf tips extended. In addition, leaf widths, leaf numbers, and plant weights were recorded. Ear leaf samples were taken at

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pollen shedding. Seedling and ear leaf samples were washed in a 1% sodium lauryl sulfate solution, double rinsed in distilled water, and dried at 60°C. Radishes were harvested prior to bolting, separated into roots and leaves, washed and dried. During thinning and harvesting, all plots subject to the same whole plot treatment (soil temperature) were removed concurrently. Dates of harvests are shown in Table 6.

TABLE 4. IRRIGATION APPLIED IN 1975 AND 1976 TO CORN PLOTS

	Treatment temperature (°C)			
	35	27	16	Ambient
	cm H_2O			
1975	18.8	10.6	3.4	10.6
1976	17.8	13.6	0.9	7.2

TABLE 5. AVERAGE RAINFALL DATA FOR 1975 AND 1976 GROWING SEASONS RECORDED AT THE PLANT RESEARCH FARM

Month	1975	1976	33 yr Average
	cm		
May	9.93	9.68	9.42
June	17.04	5.18	9.60
July	24.69	11.43	10.16
August	12.24	11.09	11.86
September	34.06	16.00	8.89

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TABLE 6. SAMPLING AND HARVESTING DATES FOR CORN PLANTED IN 1975 AND 1976

Year	Stage	Treatment temperature °C 35	27	Ambient (22)	16
		- - - - - - - - date of harvest - - - - - - - -			
1975					
	8 to 9 leaf seedling	6-20-75	6-24-75	6-27-75	7- 7-75
	ear leaf	7-21-75	7-22-75	7-25-75	8- 4-75
	mature	9- 5-75	9-10-75	9-17-75	10- 6-75
1976					
	8 to 9 leaf seedling	6-12-76	6-15-76	6-24-76	7- 9-76
	ear leaf	7-21-76	7-16-76	7-26-76	8- 6-76
	mature	9-17-76	9-24-76	10-11-76	10-14-76

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When the corn within each temperature treatment reached the hard dent stage, all three sludge treatments were harvested. Stover and grain yields were determined. Leaf counts and plant height were obtained. Plant material was sampled for dry matter determination. Grain, stover, stem, and plant leaf samples were dried prior to grinding for heavy metal analysis.

Following the removal of corn grown on the 16°C plots on September 27, 1975, the temperature regulation equipment was inactivated to allow for an equilibration of the soil temperature prior to planting winter cover crops. On 6 Oct. 1975, oats (Avena sativa L.) 'Norline', wheat (Triticum aestivum L.) 'Arthur', rye (Secale cereale L.) 'Balboa', crimson clover (Trifolium incarnatum L.) 'Auburn', and arrowleaf clover (Trifolium vesiculosum Savi) 'Yuchi', were planted in rows at rates of 35, 134, 125, 22 and 5.6 kg/ha, respectively. These crops were seeded at right angles to the corn rows with minimum soil disturbance.

Two-foot strips of the forage species planted in the fall of 1975 were harvested in the spring of 1976, washed in 1% sodium lauryl sulfate solution, rinsed, and dried prior to heavy metal analysis. Whole rye, wheat, and oat plants were harvested in the boot stage on 15 April, 27 April, and 11 May, respectively. Crimson and arrowleaf clover plants were harvested at 1/10 bloom on 27 April, and 11 May, respectively.

Radishes and field corn were planted on 14 May, 1976. Procedures for planting, thinning, and final harvesting were identical to those used in 1975. Harvest dates are shown in Table 6. The corn grown on 16°C plots was harvested following a frost on 14 October, 1976. Temperature control equipment was inactivated on this date.

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LABORATORY ANALYSES

Plant Samples

Following drying of plant samples at 60°C all plant material was ground in a Wiley Mill to pass through a two millimeter stainless steel screen and thoroughly mixed. A 2-g subsample was dry ashed at 480°C, dissolved in 2-ml concentrated HNO_3 and evaporated to dryness. The residue was then redissolved in 20-ml 1.0N HCl. Zinc, Cu, Ni, Cd, and Pb concentrations were determined with a flame atomic absorption spectrophotometer equipped with a deuterium background correction lamp.

Ear leaf samples from both years were analyzed for total N by the procedure of Nelson and Sommers (1973). Plant material used for N determination was ground through a one millimeter sieve prior to digestion. Analysis for P, K, Ca, and Mg content of ear leaf tissue was conducted at the University of Maryland Soil Testing Laboratory (Bandel, V. A., and C. E. Rivard. 1975. Soil Testing Methods. University of Maryland Soil Testing Laboratory, Agron. Mimeo No. 37). Acid detergent fiber (ADF), lignin, neutral detergent fiber (NDF), in vitro dry matter digestibility (IVDMD) and ash were determined on corn stover according to the procedures of Goering and Van Soest (1969).

Soil Samples

Soil cores were taken from each plot five times during the 1975 growing season and three times during 1976. Time intervals were 0, 3, 7, 12, 20, 40, 56, and 68 weeks. Cores were taken to a depth of 15 cm using a stainless steel soil probe. Soil samples were also taken 92 weeks after the start of the experiment to 15, 25, and 61-cm depths to evaluate heavy metal movement. Approximately five cores were randomly sampled per plot. The soil was air dried, crushed, and sieved through a two millimeter stainless steel screen.

Available metals in soil samples were determined using two methods: 1) double acid extraction, .05N HCl and .25N H_2SO_4 (Wear and Evans, 1968) and 2) DTPA extraction (Lindsay and Norvell, 1978). Double acid extraction was conducted only on the first soil sample of each growing season. DTPA and double acid filtrate was analyzed for Zn, Cu, Cd, and Ni using atomic absorption procedures. Double acid filtrate was also analyzed for Pb.

Soil samples were analyzed for organic matter content using the Walkley-Black technique (Jackson, 1970). Analysis for Mg, P, K, pH of soil samples was conducted at the University of Maryland Soil Testing Laboratory (Bandel and Rivard, 1975). Cation exchange capacity of the soil and sludge-soil mixtures was determined at the start of the experiment using the ammonium saturation technique as described by Chapman (1965).

In March 1977, 92 weeks after the start of the experiment, soil samples were taken to a 15-cm depth and water stable aggregation determined according to the procedure of Bryant et al. (1948). Bulk density was determined by taking 6.5-cm soil cores from the plots, drying and calculating weight per volume.

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Microbial Samples

Soil samples used for indicator bacterial analysis were collected, placed in sterile containers, and transported to the laboratory for analysis at 0, 21, 49, 91 and 147 days after sludge addition.

Fecal coliform numbers were determined utilizing the most probable number (MPN) technique (APHA, 1971). Five tubes of lauryl sulfate broth were inoculted at each dilution and incubated at 35°C. After 24 and 48 hours, all positive tubes were transferred to EC broth and incubated for 24 hours at 44.5°C. Fecal streptococcus numbers were determined using KF Streptococcus agar pour plates incubated at 35°C for 48 hours (APHA, 1971).

Statistical Analysis

The facilities at the University of Maryland Computer Science Center were used for data analysis. Analysis of variance and linear and multiple regression were conducted. Differences in linear regression slopes were computed using analysis of covariance.

The experimental design for the analysis of radish, corn, and soils data was a split-plot, with a split-split-plot design used for the analysis of forage data. Duncan's Multiple Range Test was used to statistically separate treatment means (Duncan, 1955).

To determine regression equations for temperature and sludge application effect on stover and grain yields, the following procedure was followed. An analysis of variance was conducted to determine the significance of orthogonal polynomials in influencing the variables observed. These included linear and quadratic sludge rate components (S^1 and S^2), linear, quadratic, and cubic soil temperature components (T^1, T^2, and T^3) and sludge x soil temperature interactions (S^1T^1, S^1T^2, S^1T^3, S^2T^1, S^2T^2, S^2T^3). Those factors significant at the 5% level according to ANOVA were forced into a multiple regression equation. Partial regression coefficients are shown in the equations. The order of the independent variables in the regression equation was based on the level of statistical significance.

Main and interaction effects due to temperature, sludge, and time on fecal coliform and fecal streptococcus numbers were analyzed by least squares multivariate analysis of variance techniques and significant effect means were subjected to Duncan's Multiple Range comparison of means test at the 5% level. The regression of fecal coliforms and fecal streptococci values on time was determined with polynomial (first and second degree) regression analysis. Values for 99.9% reduction (days) and survival rate constants (K_{10} $days^{-1}$) were calculated with the chosen regression equations.

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SECTION 5

RESULTS AND DISCUSSION

CORN DEVELOPMENT

Seedlings

Corn emergence and seedling growth were accelerated at higher soil temperatures. Corn planted on plots subjected to soil temperature regimes of 27 and 35°C emerged and grew vigorously approximately five days before that in 16°C soil temperature plots. Ear leaf sampling and final harvests occurred earliest on 35°C temperature plots with 16°C plots harvested approximately one month later each year (Table 6).

Seedling dry weights per plant decreased as soil temperatures increased in both 1975 and 1976 (Table 7). Dry weights were significantly lower at 35 than at 16°C. Since seedlings were harvested on the basis of physiological maturity (leaf stage), plants growing at higher soil temperatures were harvested earlier than those growing at 16°C soil temperatures. With reduced growth rates, plants growing at lower temperatures are able to undergo increased cellular differentiation and have a smaller surface area per unit of weight (Brouwer et al. 1973).

Plant height as measured by extended leaf tips displayed a response to soil temperature similar to that of plant dry weights (Table 7). Plants grown at 35°C were significantly shorter than those grown at 16°C. Plants subjected to a 16°C soil temperature had significantly smaller leaf widths than plants grown at other soil temperatures. Research has shown that low temperatures result in a decreased rate of corn leaf development (Barlow et al. 1976). If seedling measurements were taken according to chronological age instead of physiological development, plants grown at a 35°C soil temperature would have had higher weights, heights, and leaf widths than those grown at 16°C.

Sewage sludge application had no observable effects on corn germination. In 1975, seedlings from check plots had significantly greater weights, heights, and leaf widths than those grown on sludge amended plots, but in 1976 seedlings from sludge plots were taller, had wider leaves and weighed more.

Stover and Grain Yields

In 1975, a soil temperature increase from 16°C to ambient (22°C)

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TABLE 7. AVERAGE DRY WEIGHTS PER PLANT, PLANT HEIGHT, AND LEAF WIDTH VALUES FOR 8-9-LEAF SEEDLINGS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION IN 1975 AND 1976

Treatment	1975			1976		
	Weight	Height	Width	Weight	Height	Width
Soil temperature (C)*	---g---	------cm-------		---g---	------cm-------	
16	7.15a#	103.4a	6.29c	5.52a	93.3a	5.40b
Ambient (22)	5.90b	96.6b	6.83a	5.40ab	92.6a	6.27a
27	6.27b	89.4c	6.72ab	4.66c	82.9b	5.30b
35	4.92c	76.6d	6.54b	4.80bc	77.7c	6.92a
Sludge rate (Mt/ha)+						
0	6.54a	95.7a	6.89a	4.97a	84.6b	5.66c
56	5.86b	90.6b	6.53b	5.08a	87.7a	5.88b
112	5.78b	88.2b	6.38b	5.23a	87.6a	6.38a

* Values for soil temperatures are across all sludge rates. Temperature sludge interactions were not significant.

\# Values within column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range test.

\+ Values for sludges are across all temperatures.

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resulted in the largest change in grain and stover yields (Figure 1), but no significant effects occurred when temperature increased above ambient, although from 27 to 35°C yields decreased (Appendix C). Within a given soil temperature in 1975, sludge application had no significant effect on stover yields, but grain yields at 16°C were increased significantly by sludge application.

In 1976, temperature and sludge effects on yield were more pronounced than in 1975 (Figure 2). Highest grain and stover yields were at 35°C for all sludge rates. Yields of stover and grain increased at above ambient soil temperatures with highest yields occurring for 35 and 27°C plots amended with 112 and 56 metric tons/ha sludge. Plots without sludge addition had significantly lower grain yields at all soil temperatures, but stover yields at 16°C were not significantly affected by sludge addition, and at other soil temperatures 0 and 56 ton sludge treatments were not significantly different.

Soil temperature and sewage sludge application rate effects on plant height and node number are shown in Table 8. Interactions were not significant. Plant height and node numbers were significantly higher at 35 than at 16°C in both 1975 and 1976. Temperature and sludge effects on height and node numbers in 1976 appear to coincide with those observed for grain and stover yields.

Differences in yield response between 1975 and 1976 are difficult to explain since the same variety was used. The increased yield in 1976 due to 35°C soil heating agrees with the results of Rykbost et al. (1975) who observed a yield increase due to soil heating to temperatures of 35 to 38°C. Results in 1975 were similar to those of Decker and Walker (1973) who found that final corn grain and stover yields were greatest at soil temperatures of 25°C and ambient, but were decreased at 16 and 35°C.

Although high temperatures increase CO_2 fixation and plant metabolic activity, dry matter production is usually decreased due to high rates of plant respiration (Thompson, 1966; Aldrich et al. 1975). Runge (1968) reported that temperatures of 32 to 38°C could be beneficial to corn yields if adequate moisture was available. This would explain the decreases in grain and stover yields in 1975 at above ambient soil temperature, but in 1976 plant yields were highest at 35°C. Corn was planted in 1976 on 14 May, two weeks earlier than in 1975. Ambient air temperatures for this period averaged 17°C. Runge and Odell (1958) and Thompson (1969) reported that high temperatures during seedling growth in May and June could be beneficial to final corn yields. Below normal temperatures during seedling development have been reported to decrease growth potential and final yields (Lai, 1974; Thompson, 1969). The increase in yields which occurred in 1976 at above ambient temperatures might be attributed to stimulatory effects of high soil temperature during seedling development.

Sewage sludge effects on yields can be attributed to the application of plant nutrients and organic matter to the soil. Organic matter acts to buffer against changes in soil pH. The pH of check plots in both 1975 and 1976 was below the range of 5.6 to 7.5 considered optimum for corn production (Table 2) (Aldrich et al. 1975). The low soil pH, and plant N and P levels observed for

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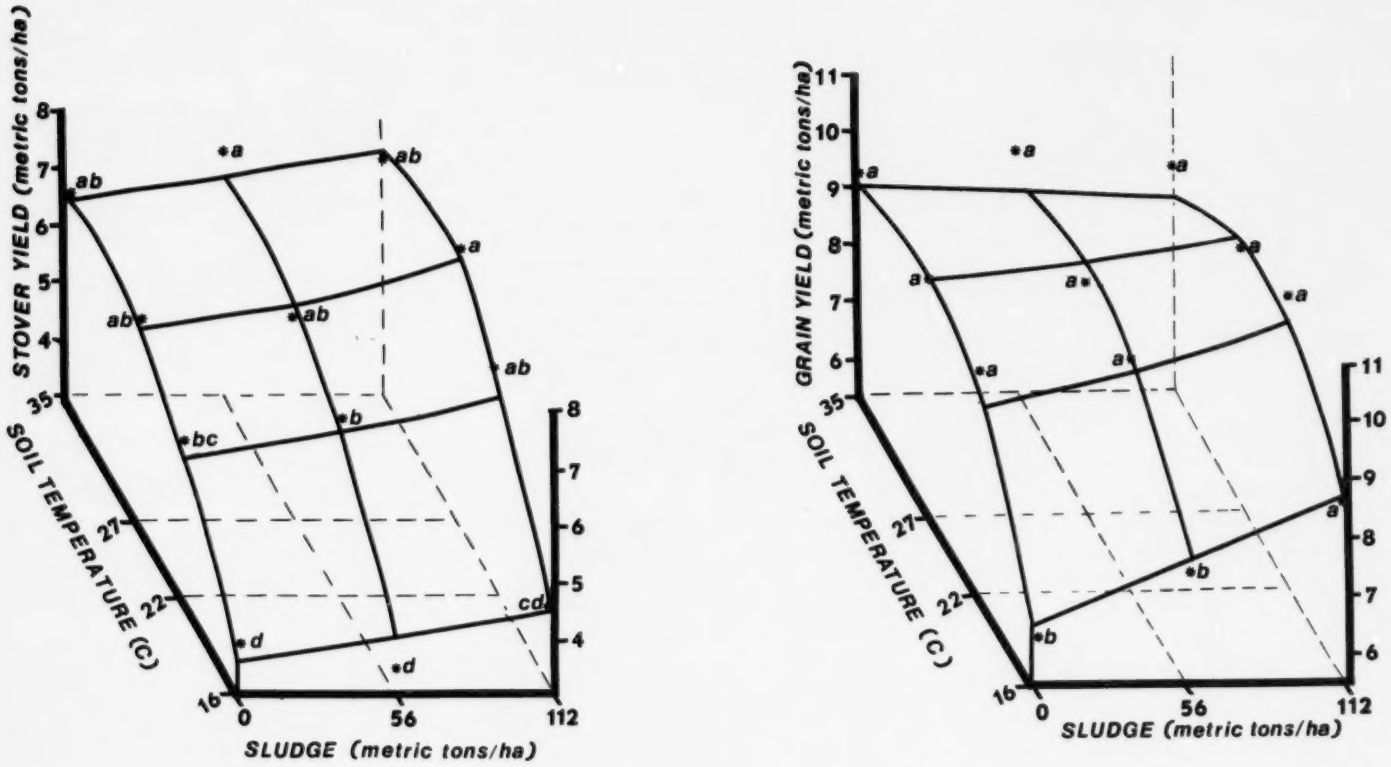

Figure 1. Stover and grain yields in 1975 as a function of soil temperature and sewage sludge application rates. Regression equations and R^2 values for stover and grain response surfaces are: $Y = -6.66 + .89T + .0072S - .0147T^2$ and $R^2 = .82$; and $Y = -4.72 + .038S + .96T - .0011TS - .0162T^2$, $R^2 = .68$, respectively.
Treatment mean values are indicated on the response surfaces by asterisks. Values with the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

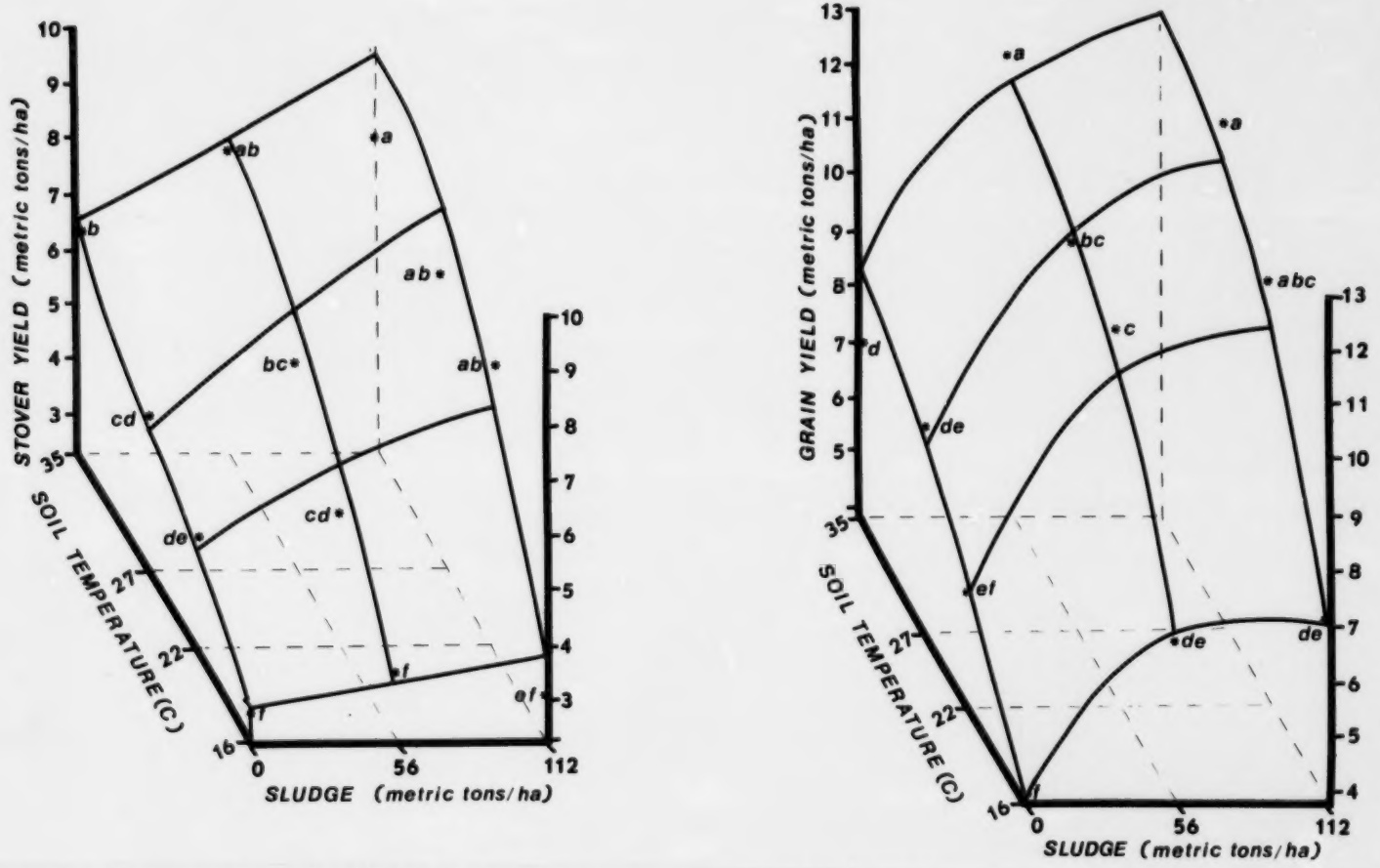

Figure 2. Stover and grain yields in 1976 as a function of soil temperature and sewage sludge application rates. Regression equations and R^2 values for stover and grain response surfaces are: $Y = -.075 - .067S + .191T + .0052TS - .206 \times 10^{-5} T^3S$, $R^2 = .89$; and $Y = -5.42 - .015S + .74T + .0084TS - .01T^2 - .046 \times 10^{-2}S^2 - .015 \times 10^{-2}T^2S$, $R^2 = .94$, respectively. Mean values are indicated by asterisks. Values with the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

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TABLE 8. AVERAGE CORN HEIGHTS AND NODE NUMBERS AS INFLUENCED BY SEWAGE SLUDGE APPLICATION AND SOIL TEMPERATURE

Treatment	1975 Height (m)	1976 Height (m)	1975 Node no.	1976 Node no.
Soil temperature (°C)				
16	2.20b*	1.77d	11.7c	11.2b
Ambient	2.52a	2.00c	12.5b	11.7b
27	2.55a	2.15b	12.6b	13.0a
35	2.51a	2.21a	13.5a	12.8a
Sludge rate (metric tons/ha)				
0	2.40a	1.96c	12.5a	12.2a
56	2.42a	2.05b	12.4a	12.2a
112	2.51a	2.09a	12.9a	12.2a

* Means followed by same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

1976 check plots (zero sludge) may have been related to the yield reduction observed (Tables 2 and 9).

Stover Forage Quality

In 1975 and 1976, similar temperature and sludge effects on stover constituents used to indicate forage quality were observed. Temperature x sludge interactions were not significant and effects of main treatments for 1976 are shown in Table 10. Stover from 16°C soil temperature plots had significantly lower ADF and lignin levels than at 35°C. Digestibility (IVDMD) increased with decreasing soil temperatures although not significantly. Cell wall content (NDF) was not affected by soil temperature. Deninum and Darven (1971) had observed similar temperature effects with maize and attributed it to decreased lignin biosynthesis and stem elongation at lower temperatures.

Sewage sludge application resulted in ADF and lignin increases while IVDMD and NDF decreased. These changes in forage quality are probably related to plant growth. Plants grown on check plots were stunted and had lower dry matter production than those to which sludge was applied.

Ear Leaf Macronutrients

Ear leaf N, P, and K concentrations were higher in both years of the experiment at 35 than 16°C (Table 9). However, levels of N, P, and K in ear leaves from 35°C plots were not always significantly different from 27°C and

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TABLE 9. AVERAGE N, P, K, MG AND CA CONCENTRATIONS IN CORN EAR LEAVES AS AFFECTED BY SEWAGE SLUDGE APPLICATIONS AND SOIL TEMPERATURES, 1975 AND 1976

Year	Treatment		Element N	P	K	Mg	Ca
			%				
1975	Soil temperature (C)	16	2.60 C*	0.25 B	1.87 B	0.23 A	0.55 A
		22 (Amb)	2.97 B	0.37 A	2.17 A	0.24 A	0.51 B
		27	3.13 AB	0.40 A	2.23 A	0.21 AB	0.44 C
		35	3.16 A	0.40 A	2.38 A	0.18 B	0.48 BC
	Sludge rate (metric tons/ha)	0	2.90 B	0.33 C	2.25 A	0.19 C	0.41 C
		56	2.94 AB	0.38 A	2.23 A	0.21 B	0.48 B
		112	3.05 A	0.35 B	2.01 B	0.24 A	0.58 A
1976	Soil temperature (C)	16	2.12 A	0.34 B	1.68 BC	0.18 D	0.44 A
		22 (Amb)	2.33 A	0.50 A	1.55 C	0.26 B	0.40 B
		27	2.39 A	0.45 A	1.74 B	0.28 A	0.40 B
		35	2.36 A	0.43 A	2.04 A	0.23 C	0.40 B
	Sludge rate (metric tons/ha)	0	1.96 C	0.34 C	1.77 A	0.22 B	0.33 C
		56	2.33 B	0.51 A	1.81 A	0.24 A	0.41 B
		112	2.61 A	0.43 B	1.68 A	0.25 A	0.49 A

* Means within columns for years, sludge rates and temperatures followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

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TABLE 10. EFFECTS OF SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION RATE ON ACID DETERGENT FIBER (ADF), LIGNIN, IN VITRO DRY MATTER DIGESTIBILITY (IVDMD), NEUTRAL DETERGENT FIBER (NDF), AND ASH CONTENT OF CORN STOVER IN 1976

		ADF	Lignin	IVDMD	NDF	Ash
		- - - - - - - - - - - - % - - - - - - - - - - -				
Soil temperature (°C)	16	39.8b*	3.83b	61.8a	71.5a	1.71a
	22	43.6ab	4.21b	58.0a	74.6a	1.83a
	27	45.7a	5.13ab	57.5a	73.8a	2.09a
	35	47.2a	6.12a	55.7a	71.4a	2.13a
Sludge rate MT/ha	0	42.4b	4.25a	61.2a	73.8a	1.96a
	56	45.7a	5.08a	55.4b	74.6a	2.07a
	112	43.7ab	5.14a	58.2ab	70.0b	1.80a

* Means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

ambient (22°C) temperature treatments. Calcium levels were significantly higher at 16 than 35°C in 1975 and 1976. This was also observed for Mg in 1975.

Low soil temperatures have been shown to decrease plant metabolic activity, translocation, root growth, and nutrient mass flow and diffusion (Nielsen, 1974). While these processes were not evaluated in this study, they may have interacted to decrease nutrient uptake and ear leaf nutrient levels of N, P, and K at the 16°C soil temperature.

Lower levels of Ca observed in ear leaves from 35°C plots and a failure of seedling leaves to unfold from the whorl were also observed by Walker (1969) who found a Ca deficiency in corn leaves which was associated with Ca immobilization in the stems. Mederski and Jones (1963) attributed low concentrations of Ca and Mg in seedlings grown on high temperature plots to cation competition due to increased K uptake and dry matter dilution.

Increased N, P, Ca, and Mg concentrations in corn ear leaves occurred due to sewage sludge application in 1975 and 1976 (Table 9). Potassium levels decreased with sewage sludge application. A significant temperature x sludge interaction occurred for N in 1975 (Appendix D, Table D-1). Highest concentrations occurred in plots subjected to a 35°C soil temperature and amended with 56 and 112 metric ton/ha sludge. Concentrations were lowest at all sludge rates for the 16°C temperature plots.

Terman et al. (1976) indicated the problems of interpreting nutrient

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concentration data in which dry matter production is affected by treatments. It is possible that N, P, and K concentration increases observed in 1975 at higher soil temperatures were a result of a decrease in dry matter production but concentration decreases would then have been expected in 1976 when dry matter production increased at high soil temperatures; this was not observed.

Adequate amounts of N should have been available from sludge-amended and check plots due to mineralization of organic compounds and fertilization in both 1975 and 1976. The sufficiency range for N in corn leaves is 2.76 to 3.50% (Jones, 1968). Levels of N in corn ear leaves were below this for 16°C temperature plots in 1975 and for most plots in 1976. These deficiencies undoubtedly were related to the low yields from check plots in 1976 and 16°C temperature plots in both years. Despite the lower N levels in plant material in 1976, grain yields from sludge-amended plots were higher than in 1975.

Nitrogen and P levels were reduced in corn ear leaves at the 16°C soil temperature and were not supplied adequately by any of the sludge treatments. This may be related to the low temperature yield depression, but it is difficult to explain the variation in yields which occurred at above ambient soil temperatures on the basis of plant macronutrient status.

PLANT HEAVY METALS

Corn

9-1/8"

An increase in Zn, Cu, Cd, and Ni concentrations in all corn materials occurred as a result of sewage sludge application (Appendix E, Tables E-1-9). This has also been observed by researchers with other agronomic crops as well as corn (Kelling et al. 1977; Kirkham, 1976; CAST, 1976). Due to the high concentrations of Zn and Cu in the sludge, these elements were present in the largest amounts in aerial portions of the plant.

A significant positive linear relationship existed between sludge application and Zn concentrations in all plant material (Figures 3-6), but means obtained by averaging concentrations across all soil temperatures (indicated by dotted line on graphs) indicated that a non-linear relationship often better explained the plant concentration response to sludge application. Pooled regression lines are shown when slopes (change in plant concentration per unit of sludge applied) and intercepts (plant concentrations when no sludge was applied) were not significantly different for soil temperatures.

At above ambient soil temperatures (27 and 35°C) Zn concentration changes in 1976 ear leaves and in 1975 grain per unit of sludge addition were significantly greater than at 16°C and ambient (22°C). For most plant materials analyzed, average Zn concentrations were lower at 16°C than at 35°C. High levels of Zn in stover from 16°C temperature plots may be due to the stunting of plant growth and to low dry matter production (Figures 1 and 2). Reduced plant Zn concentrations and deficiencies at low soil temperatures were reported by Bauer and Lindsay, 1965 and Ellis et al. 1964.

Although sludge application effects were significant for Cu, Cd, and Ni,

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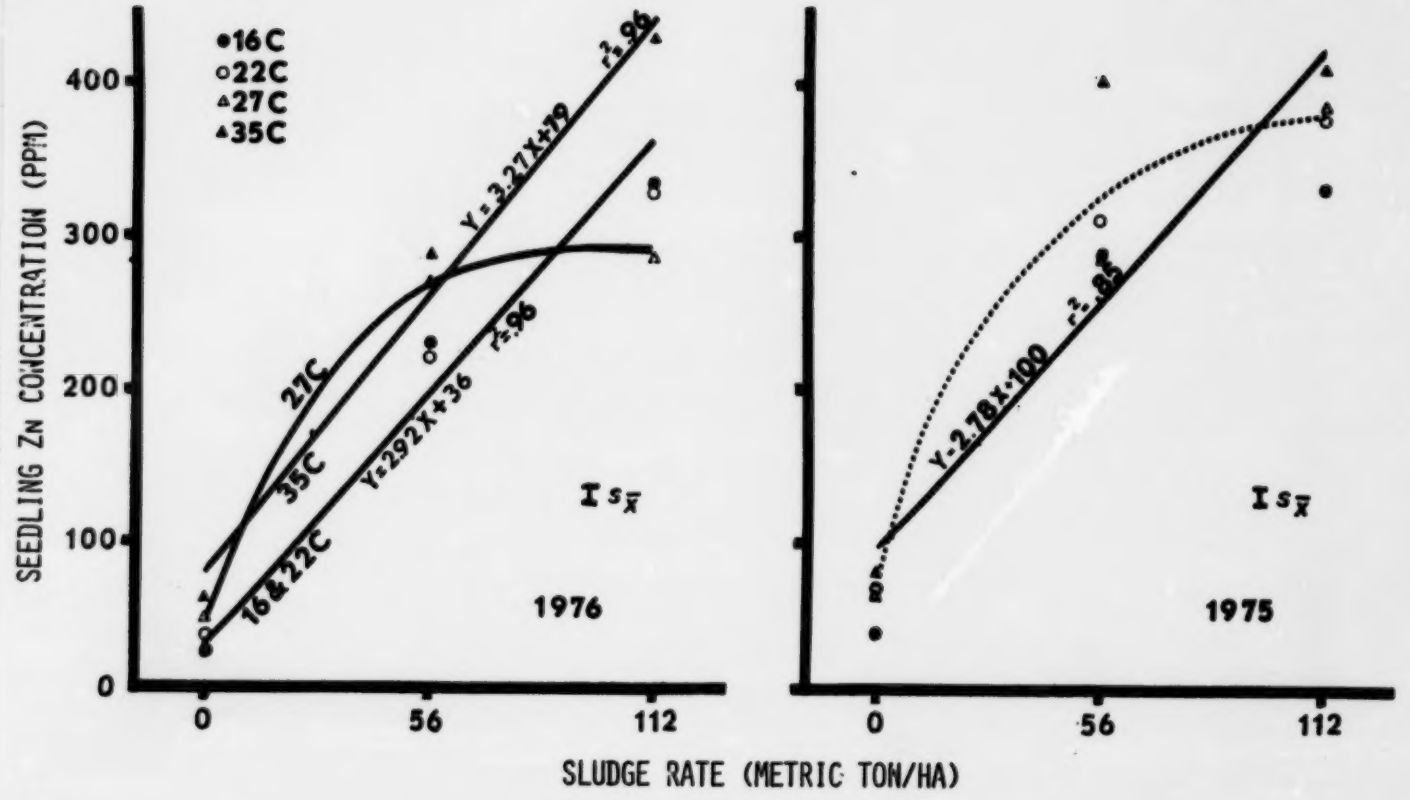

Figure 3. Soil temperature and sewage sludge effects on seedling Zn concentrations. Linear regression was conducted for each soil temperature and where slope did not differ, a pooled regression line is shown. Dotted line represents non-linear response and is based on an average of all temperatures.

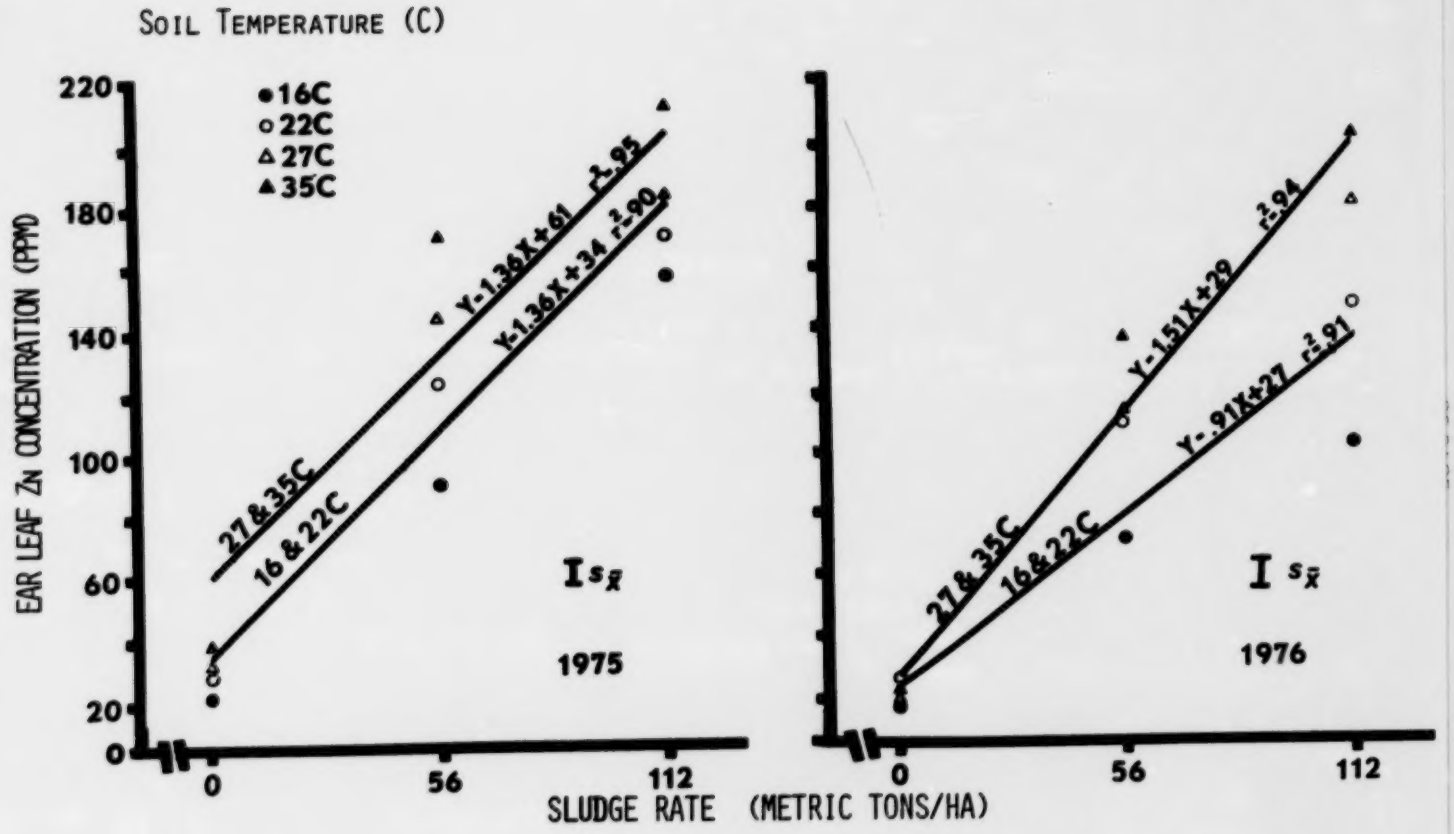

Figure 4. Soil temperature and sewage sludge effects on ear leaf Zn concentrations. Linear regression was conducted for each soil temperature and where slopes and elevations did not differ, a pooled regression line is shown.

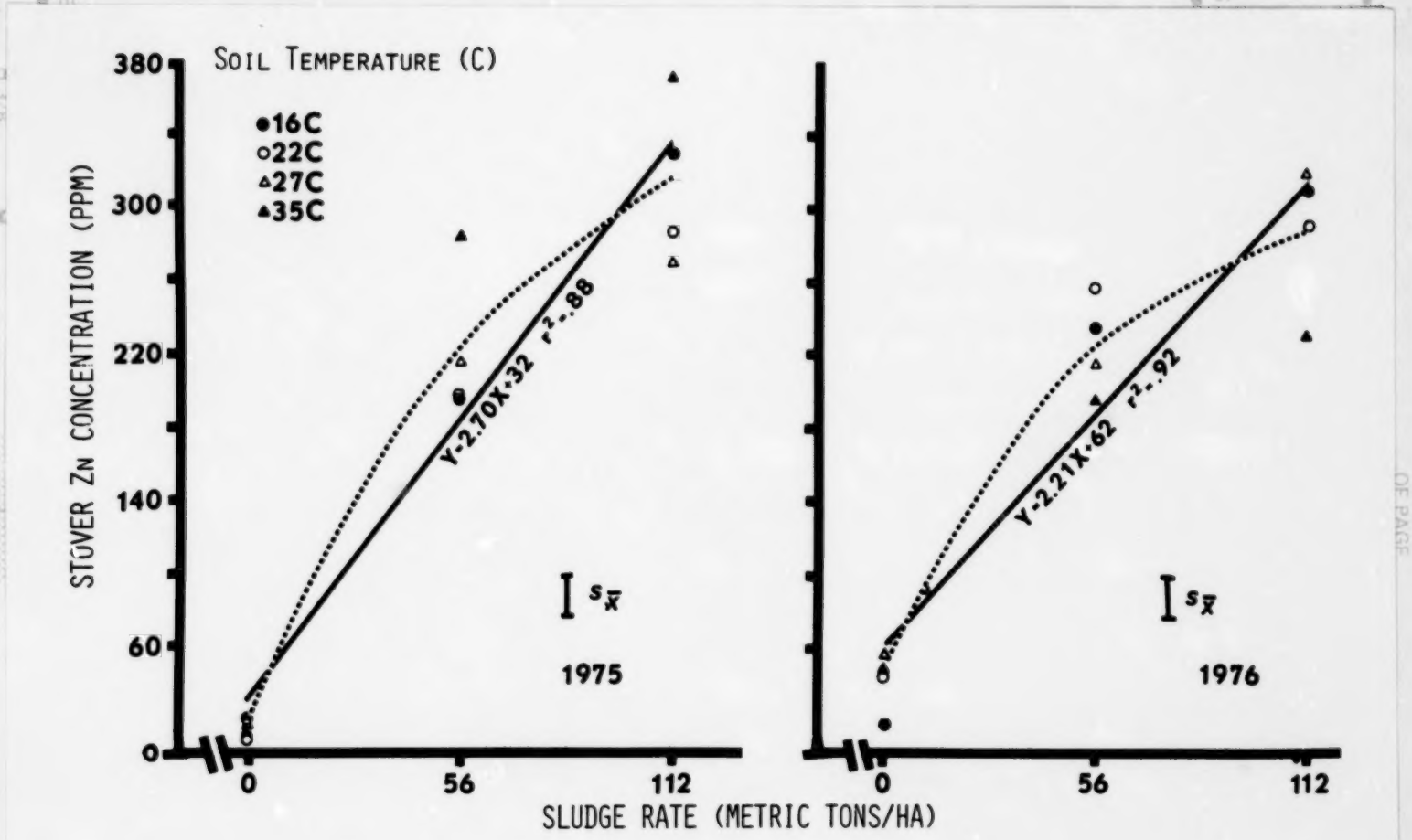

Figure 5. Soil temperature and sewage sludge effects on corn stover Zn concentration. Linear regression was conducted for each soil temperature and where slope did not differ, a pooled regression line is shown. Dotted line represents non-linear response and is based on an average of all temperatures.

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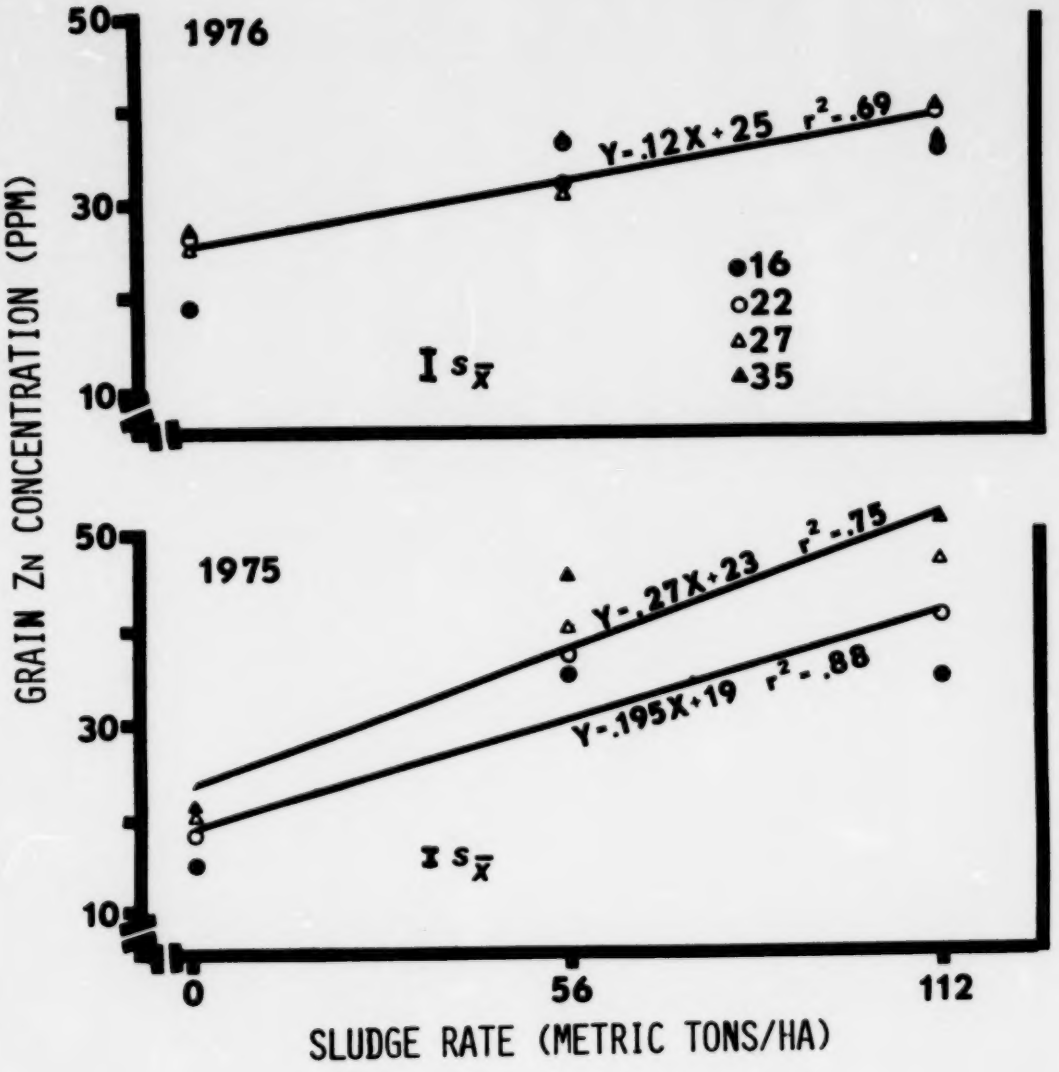

Figure 6. Soil temperature and sludge effects on grain Zn concentrations. Linear regression was conducted for each soil temperature and where slopes and elevations did not differ, a pooled regression is shown.

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the changes in metal contents in response to sludge application were variable among plant materials and not always linear (Tables 11-14). Concentrations of Pb in plant material did not increase as a result of sewage sludge application, but did decrease significantly in 1976 ear leaf material.

Copper, Cd, Ni, and Pb levels in plant material did not display temperature effects as much as Zn. This may be related to the lack of Cu, Ni, and Pb translocation to aerial portions of the plants (Chaney and Giordano, 1977) and to the low concentrations of Cd found in the sewage sludge (Table 1). Effects of temperature treatments on dry matter production may act to mask changes in nutrients which are present in low concentrations (Terman and Noggle, 1973).

Copper concentrations in seedlings were significantly higher each year at 35 versus 16°C soil temperatures (Figure 7). This was also observed in 1976 ear leaves and stover (Tables 11-14). The high levels of Cu found in 1975 ear leaves at 16°C for 56 and 112 ton sludge additions may be due to a reduced dry matter production at that temperature (Figure 8). Cadmium concentrations in ear leaves and seedlings for 1975 and 1976 were also significantly higher at 35 versus 16°C. Giordano and Mays (1977) observed an increased concentration of Cd, Zn and Cu in corn leaves as a result of soil heating. Despite the low concentrations in the sludge (16 ppm) relatively large amounts of Cd were taken up and translocated to portions of the plant (Appendix E).

9-1/8"

Nickel and Pb concentrations were not consistently affected by soil temperature. Higher Ni levels were found in grain in 1976 at 35°C than at 16°C soil temperatures, but for other plant material, effects due to high and low temperatures were not noted. In 1975, seedling Pb concentrations were significantly higher at 35°C than other soil temperatures, but this was the only temperature response noted.

Plants harvested at the seedling stage had the highest concentration of heavy metals, and the grain the lowest. Changes in concentration per unit of sludge applied were also greatest for seedlings and least for grain. In seedlings, dry matter production is less than rates of metal uptake, whereas in more mature plant material, high dry matter production occurs (Terman and Noggle, 1973). Grain concentrations are low due to a lack of translocation of metals (Chaney and Giordano, 1977). Ear leaf Cd and Cu levels may also be reduced due to an accumulation in the stalk (Kirkham, 1975).

Forages

Following removal of the corn in the fall of 1975, legumes and small grains were seeded into the plots and harvested in the spring of 1976. They served as cover crops and aided in evaluating the residual effects of soil temperature and sewage sludge application on plant growth and heavy metal uptake. No plant yields were taken but field observations indicated that wheat, oats, and rye growth was greatest on sludge-amended plots with smaller, less vigorous plants on check plots. The reverse was true for crimson and arrowleaf clover, for larger plants were observed on the check plots. No observable growth effects of soil temperature were noted. The high N levels of

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TABLE 11. AVERAGE CD, NI, AND PB CONCENTRATIONS OF 8 TO 9-LEAF SEEDLINGS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Treatment	Cd		Ni		Pb	
	1975	1976	1975	1976	1975	1976
	µg/g					
Soil temperature (C)						
16*	.74C#	.76B	1.61A	1.10A	0.90B	1.20A
22 (ambient)	.86B	.69B	1.78A	1.36A	0.97B	0.84A
27	.76C	.85AB	1.69A	1.24A	0.97B	0.55A
35	1.10A	1.02A	1.57A	1.18A	1.46A	0.77A
Sludge rate (metric tons/ha)						
0+	.67C	.41B	1.21C	.65C	1.06A	0.75A
56	1.09A	1.00A	1.56BC	1.14B	0.89A	0.69A
112	.86B	1.07A	2.14A	1.86A	1.26A	1.01A

* Soil temperature means are across all sludge rates.

\# Soil temperature and sludge rate means within metals for 1975 or 1976 followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's Multiple Range Test.

\+ Sludge rate means are across all soil temperatures.

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TABLE 12. AVERAGE CD, NI, AND PB CONCENTRATIONS OF CORN EAR LEAVES IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Treatment	Cd		Ni		Pb	
	1975	1976	1975	1976	1975	1976
	- - - - - - - - - - - - µg/g - - - - - - - - - - - -					
Soil temperature (C)						
16*	.29B#	.27B	.49A	.59B	1.88B	2.49A
22 (ambient)	.34A	.36B	.65A	1.46A	2.72A	2.36A
27	.36A	.32B	.48A	1.21AB	2.00B	2.67A
35	.33A	.55A	.49A	.95AB	2.00B	2.61A
Sludge rate (metric ton/ha)						
0+	.18B	.25B	.36B	.87B	2.34A	1.88A
56	.45A	.44A	.50AB	1.02AB	1.98B	1.47AB
112	.45A	.45A	.72A	1.26A	2.12A	1.52B

* Soil temperature means are across all sludge rates.

\# Soil temperature and sludge rate means within metals for 1975 or 1976 followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's Multiple Range Test.

\+ Sludge rate means are across all soil temperatures.

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TABLE 13. AVERAGE CU, CD, NI, AND PB CONCENTRATIONS OF CORN GRAIN AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATIONS, 1975 AND 1976

Treatment	Cu		Cd		Ni		Pb	
	1975	1976	1975	1976	1975	1976	1975	1976
	µg/g							
Soil temperature* (C)								
16	1.81A#	1.65A	.09AB	.09A	1.07A	0.79B	.08A	.10A
22 (ambient)	1.53A	1.72A	.08AB	.09A	1.01A	0.80B	.12A	.06B
27	1.79A	1.64A	.07B	.07B	0.85A	0.71B	.07A	.09A
35	2.14A	1.70A	.10A	.07B	0.87A	1.00A	.12A	.06B
Sludge rate+ (metric tons/ha)								
0	1.52C	1.57A	.05B	.06B	0.29C	0.48C	.12A	.06A
56	1.87A	1.69A	.10A	.09A	0.95B	0.84B	.07A	.09A
112	1.75B	1.73A	.12A	.10A	1.61A	1.16A	.10A	.08A

* Soil temperature means are across all sludge rates.

\# Soil temperature and sludge rate means within metals for 1975 or 1976 followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's Multiple Range Test.

\+ Sludge rate means are across all soil temperatures.

TABLE 14. AVERAGE CU, CD, NI, AND PB CONCENTRATIONS OF CORN STOVER AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION, 1975 AND 1976.

Treatment	Cu		Cd		Ni		Pb	
	1975	1976	1975	1976	1975	1976	1975	1976
	µg/g							
Soil temperature* (C)								
16	6.35B#	3.94A	1.09A	0.36A	0.45A	0.74A	1.88B	2.49A
22 (ambient)	8.14A	4.08A	0.66A	0.56A	1.59A	0.74A	2.72A	2.37A
27	8.59A	4.62A	0.72A	0.41A	0.76A	0.64A	2.00B	2.67A
35	8.40A	4.62A	0.86A	0.46A	0.84A	0.79A	2.00B	2.61A
Sludge rate+ (metric tons/ha)								
0	6.43C	4.05A	0.37B	0.34B	0.74A	0.57B	2.34A	3.21A
56	7.50B	4.83A	1.07A	0.59A	1.27A	0.90A	1.98A	2.50AB
112	9.59A	4.08A	1.05A	0.42B	0.72A	0.69B	2.12A	1.91B

* Soil temperature means are across all sludge rates.

\# Soil temperature and sludge rate means within metals for 1975 or 1976 followed by the same letter are not significantly different at the 5% level of significance as determined by Duncan's Multiple Range Test.

\+ Sludge rate means are across all soil temperatures.

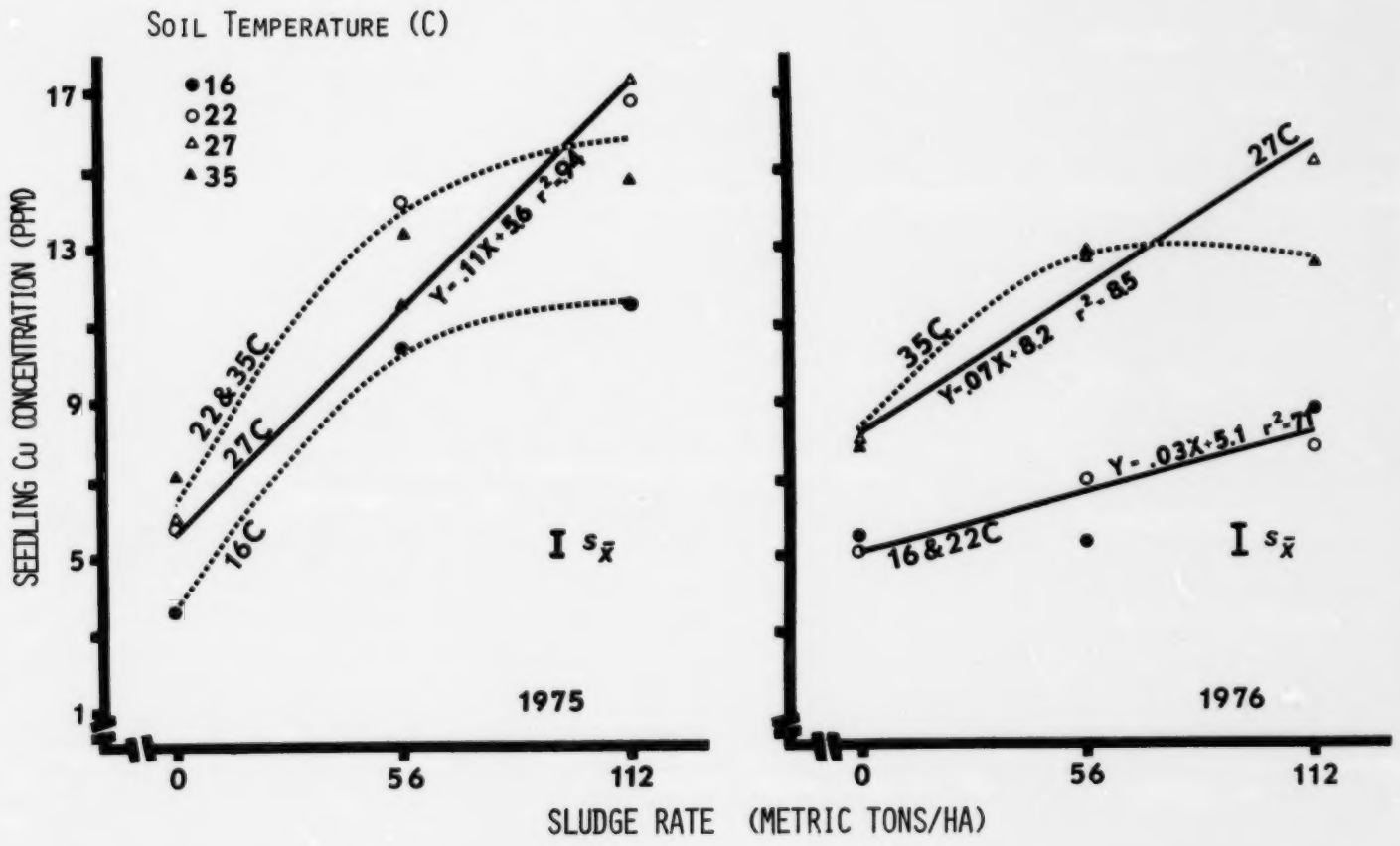

Figure 7. Soil temperature and sludge effects of seedling Cu concentrations. Linear regression was conducted for each soil temperature and where slopes and elevations did not differ, a pooled regression line was used. Dotted lines are average values for temperatures for which a non-linear line fit best.

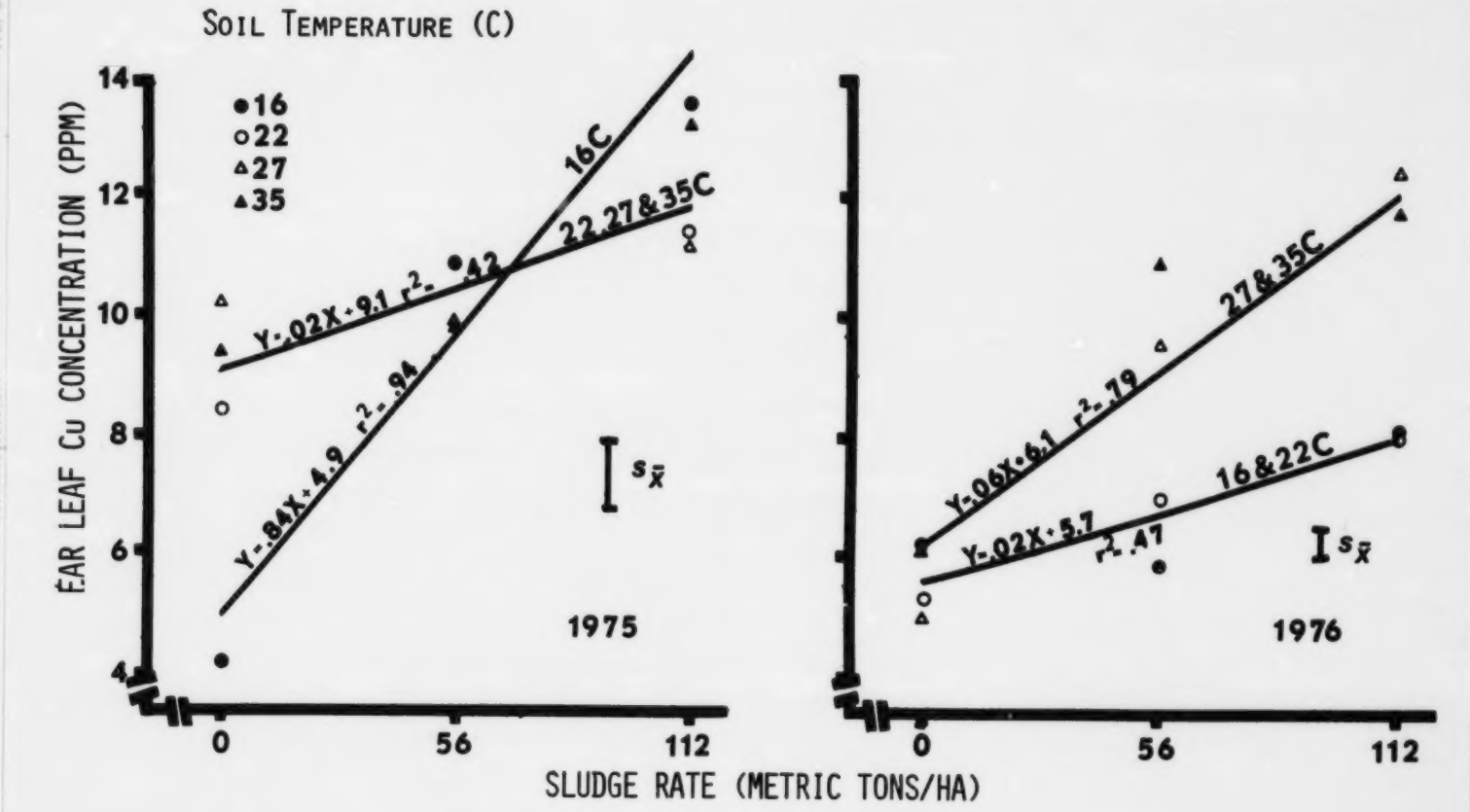

Figure 8. Soil temperature and sewage sludge effects on ear leaf Cu concentrations. Linear regression was conducted for each soil temperature and where slopes and elevations did not differ, a pooled regression line is shown.

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plots amended with sewage sludge probably promoted growth of the small grains but retarded growth of the legumes. King and Morris (1972) observed increased rye yields due to liquid sewage sludge application. Day and Tucker (1959) and Day et al. (1962) reported higher wheat, barley, and oat hay and grain yields due to waste water application. These growth responses were attributed to the N, P, K, and organic matter supplied to the soil. Heavy metals found in sewage sludge have been reported to be antagonistic to legume nodulation (McIlveen and Cole, 1974).

Significant differences in heavy metal concentrations existed among forages (Table 15). For all metals evaluated, significantly higher concentrations were found in arrowleaf clover grown in 112 ton sludge plots than in other forages. Crimson clover grown on sludge-amended plots had significantly higher concentrations of Zn, Cu, and Pb than the small grains. Among the grasses, rye had the highest Zn, Cu and Pb concentrations and oats had the highest Ni concentration. Increased uptake of minerals by legumes versus grasses is generally observed and soybeans have been shown to accumulate more metals than corn (Chaney, 1973).

TABLE 15. HEAVY METAL CONCENTRATIONS IN LEGUMES AND SMALL GRAINS AS AFFECTED BY SEWAGE SLUDGE APPLICATION

Metal	Sludge rate	Arrowleaf clover	Crimson clover	Oats	Rye	Wheat
	metric ton/ha	µg/g				
Zn	0	51 c*	50 b	13 b	21 b	19 b
	56	187 b	102 a	39 a	91 a	61 b
	112	312 a	122 a	42 a	94 a	72 a
Cu	0	7.3 c	7.1 c	1.5 b	4.5 b	2.1 b
	56	10.1 b	8.4 b	2.6 a	6.6 a	3.2 a
	112	13.9 a	9.4 a	2.5 a	6.7 a	3.7 a
Cd	0	.08c	.04b	.11a	.06b	.02b
	56	.28b	.13a	.18a	.17a	.20a
	112	.42a	.05b	.17a	.18a	.21a
Ni	0	2.3 c	1.4 b	0.7 a	0.4 b	0.4 b
	56	6.5 b	2.9 ab	5.3 b	1.1 a	1.3 a
	112	10.7 a	3.5 a	6.9 a	1.9 a	2.2 a
Pb	0	1.62a	1.30a	.72a	.93a	.39a
	56	1.60a	1.33a	.67a	.96a	.42a
	112	1.87a	1.16a	.67a	1.04a	.39a

* Values for metals within species followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

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Accumulation of heavy metals by small grains as a result of sewage sludge application has been observed by several authors, but comparisons between species have not been made (King and Morris, 1972; Bradford et al., 1975; Bingham et al., 1976). Research on uptake of heavy metals by forage legumes has been limited since work on the use of sewage sludge has dealt primarily with crops which could utilize the N supplied. For all forages grown in this experiment, large differences in Zn, Cu, Cd, and Ni concentrations occurred between the check and sludge amended plots. Plants from plots amended with 56 and 112 metric tons/ha sewage sludge had significantly higher levels of Zn, Cu, and Ni than check plots, but concentrations did not always increase significantly as sludge rates increased from 56 to 112 tons. Cadmium levels were not significantly higher in oats and wheat from plots amended with 56 tons of sludge than from the check plots.

There was no consistent residual soil temperature effect on heavy metal concentrations in forages. Effects of soil temperature on plant metal levels therefore appear to be due to a modification of plant uptake processes and not to an increased soil metal availability.

Radishes

Sewage sludge application resulted in increases in Zn, Cu, Ni, and Cd concentrations in radishes (Table 16). The increase was more pronounced in 1975 and 1976 and in tops more than roots (Appendix F, Tables F-1-4). Concentrations of Zn, Cu, Ni and Cd were greater in tops than roots for all treatments in 1975, but in 1976 several exceptions were noted. John (1973) and Lagerwerff (1971) also reported higher concentrations of Cd and Zn in radish tops than roots. Lead appeared to be more evenly distributed (Lagerwerff, 1971).

TABLE 16. AVERAGE ZN, CU, NI AND CD LEVELS IN RADISH ROOTS AND TOPS AS AFFECTED BY SEWAGE SLUDGE APPLICATION. 1975

Plant material	Sludge rate mt/ha	Zn	Cu	Ni	Cd
		µg/g			
Root	0	73 C*	6.0 C	2.7 C	0.70 C
	56	292 B	10.7 B	5.6 B	1.02 B
	112	443 A	29.7 A	8.3 A	1.38 A
Tops	0	89 C	9.6 C	2.3 C	1.34 B
	56	439 B	19.7 B	7.3 B	1.55 B
	112	770 A	39.6 A	12.5 A	2.21 A

* Means followed by same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

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In 1975, highest concentrations of Zn, Cu, Ni, and Cd were found in radishes from plots amended with 112 metric tons/ha and subjected to a soil temperature of 35°C (Table 17). These values were significantly higher for Zn and Cu but not for Ni and Cd. No significant temperature or sewage sludge effects were observed for Pb in tops or roots. Radishes grown in ambient, 27, and 35°C soil temperature plots had stunted root and top growth which possibly caused an increased concentration of heavy metals. Radishes grown at 16°C had rounded roots and large green tops. This was expected since radishes are a cool season crop and make optimum growth at low temperatures.

TABLE 17. AVERAGE ZN, CU, NI AND CD LEVELS IN RADISH ROOTS AND TOPS FROM 112 METRIC TONS/HA SLUDGE PLOTS AS AFFECTED BY SOIL TEMPERATURE. 1975

Plant material	Soil temperature	Zn	Cu	Ni	Cd
	°C	µg/g			
Roots	16	362 b*	17.9 b	8.0 a	.73 b
	22 (Ambient)	302 b	16.4 b	7.2 a	.89 b
	27	405 b	25.5 b	7.6 a	1.16 b
	35	704 a	59.2 a	10.3 a	2.73 a
Tops	16	569 b	23.2 c	9.8 b	1.32 a
	22 (Ambient)	663 b	36.1 b	10.1 b	1.78 a
	27	772 b	36.1 b	10.3 b	2.12 a
	35	1071 a	59.9 a	19.8 a	2.63 a

* Means followed by same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

In 1976, effects of soil temperature were less pronounced than in 1975. No significant temperature effects on Zn concentrations in roots or tops occurred. Significantly higher Cu concentrations occurred in radish tops from plots amended at the 112 metric ton/ha rate and subjected to a soil temperature of 35°C, but root concentrations were not significantly different from the other temperature treatments. In 1976, no significant temperature effects on Ni, Cd, or Pb levels in radish tops occurred, but Cd levels in radish roots were significantly higher at a soil temperature of 35°C.

Radishes grown at above ambient soil temperatures in 1976 were not stunted to the same extent as in 1975, but some root reduction was noted. Radishes were planted earlier in 1976 than in 1975, and thus were not subjected to high air temperatures during the initial developmental stages.

The high Zn and Cu concentrations found in radish tops and leaves in 1975 were above the levels considered to be phytotoxic. Allaway (1968) reported that Zn and Cu toxicity occurred at 400 and 30 ppm tissue concentra-

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tion, respectively. The stunting of root and top growth observed may have been caused by metal toxicity.

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SOIL

Macronutrients and pH

Sewage sludge application resulted in significant increases in soil pH at the start of the experiment (Figure 9). Initial values (t = 0) and changes from first to final soil sampling (68 weeks) were greatest for the 112 metric ton/ha sludge rate and lowest for control plots.

No significant soil temperature effects on pH occurred for samples taken in 1975 (Appendix G). For the 56-week sampling (July 17, 1976), lower values were observed for 27 and 35°C soil temperature plots than 16°C or ambient. At the 68th week, soil pH values for 35°C plots were significantly lower than those of 16°C and ambient (22°C) temperatures at all sludge rates. Values for 16 and 22°C were not significantly different at any sludge rate and an average is used in Figure 9. The 27°C pH values were significantly lower than those of 16 and 22°C for the final soil sampling at the 112 ton/ha sludge rate.

Magnesium, P, and K levels were not affected by soil temperature in 1975, but Mg, P, and K levels were lower at 35 than at 16°C for both soil samples in 1976. These differences were significant for Mg, P, and K in the 56-week sampling, but only for P and K on the final sampling date (Table 18).

The high organic matter content of the sewage sludge acts to buffer against changes in pH. However, with time, the organic N portion of sewage sludge is mineralized resulting in a decrease in pH (Chaney, 1974). The optimum temperature for organic matter decomposition and N mineralization ranges from 30 to 35°C (Alexander, 1977) so that the lower pH values found at 35 versus 16°C soil temperature in 1976, possibly can be attributed to the release of H^+ ions during N mineralization and to the production of organic acids during organic matter decomposition.

The sewage sludge applied to the plots had high levels of Mg and P (Table 1); therefore, levels of these elements would be expected to be higher in sludge amended plots. Higher soil temperatures have been reported to increase P mineralization and availability (Tisdale and Nelson, 1967). Lower Mg and K levels may also be related to the decrease in soil pH.

Heavy Metals and Organic Matter

Temperature effects on soil organic matter and DTPA metals were nonsignificant within each of the eight sampling times. However, when concentrations were averaged across all samplings (Table 19), DTPA Zn and Cu levels for 112 ton/ha sludge plots were significantly lower at 35 than 16°C soil temperatures. This was not observed for control or 56 ton/ha plots. A similar trend was observed for organic matter levels, but differences were small.

Miller (1973) reported that a maximum of 20% of the added carbon in

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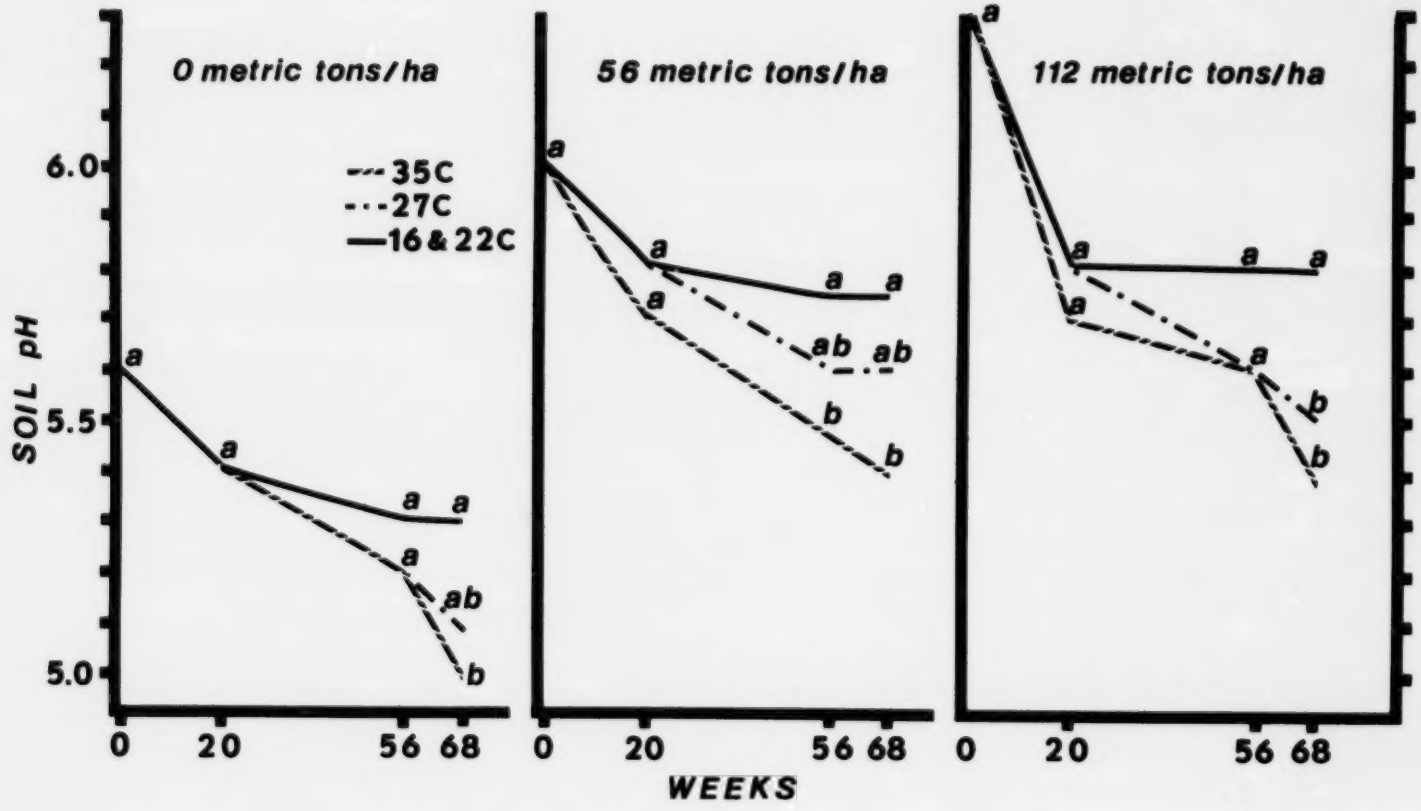

Figure 9. Effect of soil temperature (16, 22, 27, and 35°C) on pH of soil treated with 0, 56, and 112 metric tons/ha sewage sludge. Values for 22 and 22°C temperatures are represented by an average line. Values within sampling period for a given sludge treatment followed by the same letter are not significantly different at the .05 level by Duncan's Multiple Range Test.

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TABLE 18. AVERAGE pH, MG, P, AND K LEVELS IN SOIL AMENDED WITH THREE SLUDGE RATES AND SUBJECTED TO 4 SOIL TEMPERATURE REGIMES*

Sampling date	Treatment		pH	Mg	P	K
			- - - - - - - kg/ha - - - - - - - -			
5-20-75 (0 weeks)	Sludge rate (Mt/ha)	0	5.5B#	171B	184C	166B
		56	6.0A	302A	441B	185A
		112	6.2A	321A	537A	174B
10-14-76 (68 weeks)	Sludge rate (Mt/ha)	0	5.2B	100B	80C	113A
		56	5.6A	159A	288B	104A
		112	5.6A	170A	403A	100A
	Soil temperature (C) (Amb)	16 C	5.6A	156A	284A	140A
		22 C	5.5AB	138BC	260AB	92B
		27 C	5.4BC	131C	249B	90B
		35 C	5.3C	147AB	234B	101B

* Temperature data only shown for 68 week soil sampling.

\# Means within soil property followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

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TABLE 19. AVERAGE ORGANIC MATTER AND DTPA-TEA HEAVY METAL CONCENTRATIONS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION*

Variable	Soil temperature	Sludge rate metric tons/ha 0	56	112	Average
	°C		%		
Organic matter	16	1.31a#	2.25a	3.00a	2.19A
	Ambient (22)	1.28a	2.22a	2.91a	2.14A
	27	1.29a	2.12a	2.81a	2.07B
	35	1.24a	2.11a	2.77a	2.04B
	Average	1.28C	2.18B	2.87A	
			µg/g		
Zn	16	1.1d	48c	93a	47A
	Ambient (22)	1.2d	47c	90ab	46B
	27	1.1d	46c	91ab	46B
	35	1.3d	45c	86b	44C
	Average	1.2C	46B	90A	
Cu	16	0.7d	33c	62a	32A
	Ambient (22)	0.7d	34c	59ab	31A
	27	0.7d	33c	62a	32A
	35	0.7d	32c	58b	30A
	Average	0.7C	33B	60A	
Cd	16	.05a	.30a	.51a	.29A
	Ambient (22)	.05a	.30a	.49a	.28BC
	27	.05a	.31a	.49a	.28BC
	35	.04a	.30a	.46a	.27C
	Average	.05A	.30B	.49A	
Ni	16	.34a	1.59a	2.90a	1.61A
	Ambient (22)	.33a	1.54a	2.81a	1.57A
	27	.34a	1.53a	2.75a	1.54A
	35	.35a	1.55a	2.60a	1.60A
	Average	.34C	1.55B	2.76A	

* Values are across all sampling dates.

\# Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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sewage sludge decomposed within a six month period following the start of a laboratory experiment. An approximate 17% decrease in the original organic matter present occurred between the third and seventh week in plots amended with 112 tons of sewage sludge and a smaller decrease occurred from seven to twelve weeks in plots amended with 56 tons (Figure 10), (Appendix G, Table G-5). The decrease in organic matter levels observed at higher soil temperatures in this experiment was less than that reported by Miller (1973) who reported a high correlation between degree days and CO_2 evolved as a result of organic matter decomposition.

Extractable Zn and Cu levels increased significantly for all sludge rates from the first to the last soil sampling (68 weeks) (Figure 11 and 12) (Appendix G, Tables G-6 and G-7). Within each sampling date no significant differences in extractable Cu existed among soil temperatures. This was also observed for Zn levels in 56 metric tons/ha sludge plots, but significantly higher levels of DTPA extractable Zn occurred at 20 and 56 weeks in plots subjected to a soil temperature of 16 versus 35°C and amended with 112 tons of sludge (Figure 11). Cadmium and Ni exhibited no definite trends over time. The lack of a significant change in Ni and Cd concentrations could be due to variability as a result of the small amount added in the sewage sludge. Changes in the extractability of Zn and Cu were much smaller than those observed by Silviera and Sommers (1977).

Although organic matter degradation possibly increased metal availability in the soil, the lowering of soil pH also probably resulted in higher metal availability (Chaney and Giordano, 1977). Lindsay (1972) and Street et al. (1977) reported that the Zn and Cd solubility in soil solution increased 100-fold for each unit decrease in pH. Solubilities of Cu and Ni also increase at lower pH levels. Tables G-1 to G-4 (Appendix G) indicate that lower pH levels were found in 1976 than in 1975. The increase in availability of Zn and Cu from check or unamended plots in 1976 could also be explained by the decrease in pH.

A decrease in organic matter due to increases in soil temperature was expected since microbial and chemical activity both increase at higher soil temperatures (Alexander, 1977). However, only small changes in organic matter levels occurred. This may be due to the previous aerobic digestion of the sludge.

As with changes in organic matter, temperature effects on DTPA extractable metals were small. Double acid (.05N HCl and .025N H_2SO_4) extractable metal concentrations were slightly higher at 16 versus 35°C (Appendix G, Tables G-10 and G-11).

The results observed for DTPA extractable metals in this experiment disagree with the results of Giordano and Mays (1977) who observed an increase in DTPA and .5N HCl extractable metals for heated plots. Dowdy and Larson (1975) reported that incubation of a sludge-soil mixture at 33°C resulted in increased Zn and Cu availability in a soil with a low pH (5.3) but in a soil with a high pH (7.9) Zn availability did not change. This was attributed to the binding of temporarily soluble Zn (released due to organic matter degradation) by carbonates. Bauer and Lindsay (1965) also found that soil incubation

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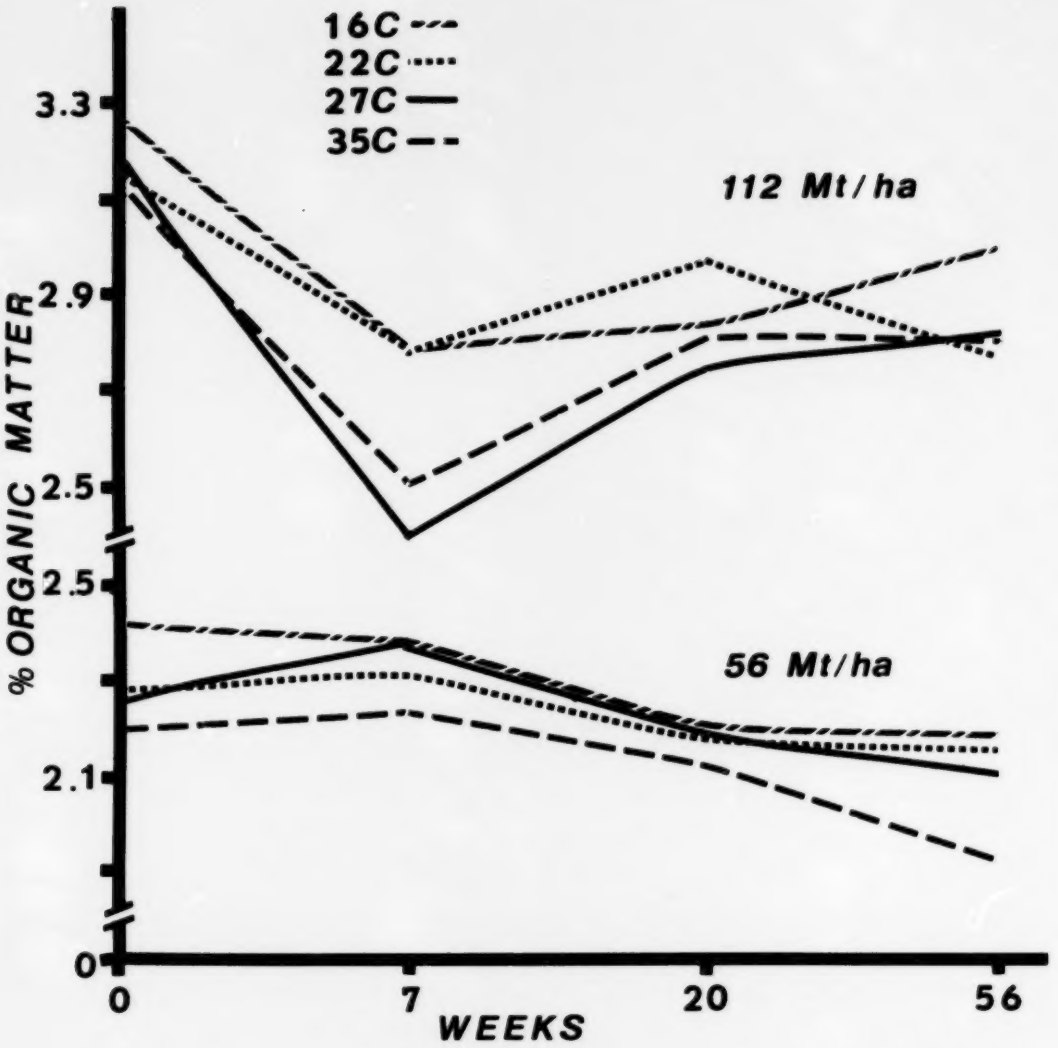

Figure 10. Average soil organic matter at several sampling dates as affected by soil temperature and sewage sludge application at rates of 56 and 112 metric tons/ha.

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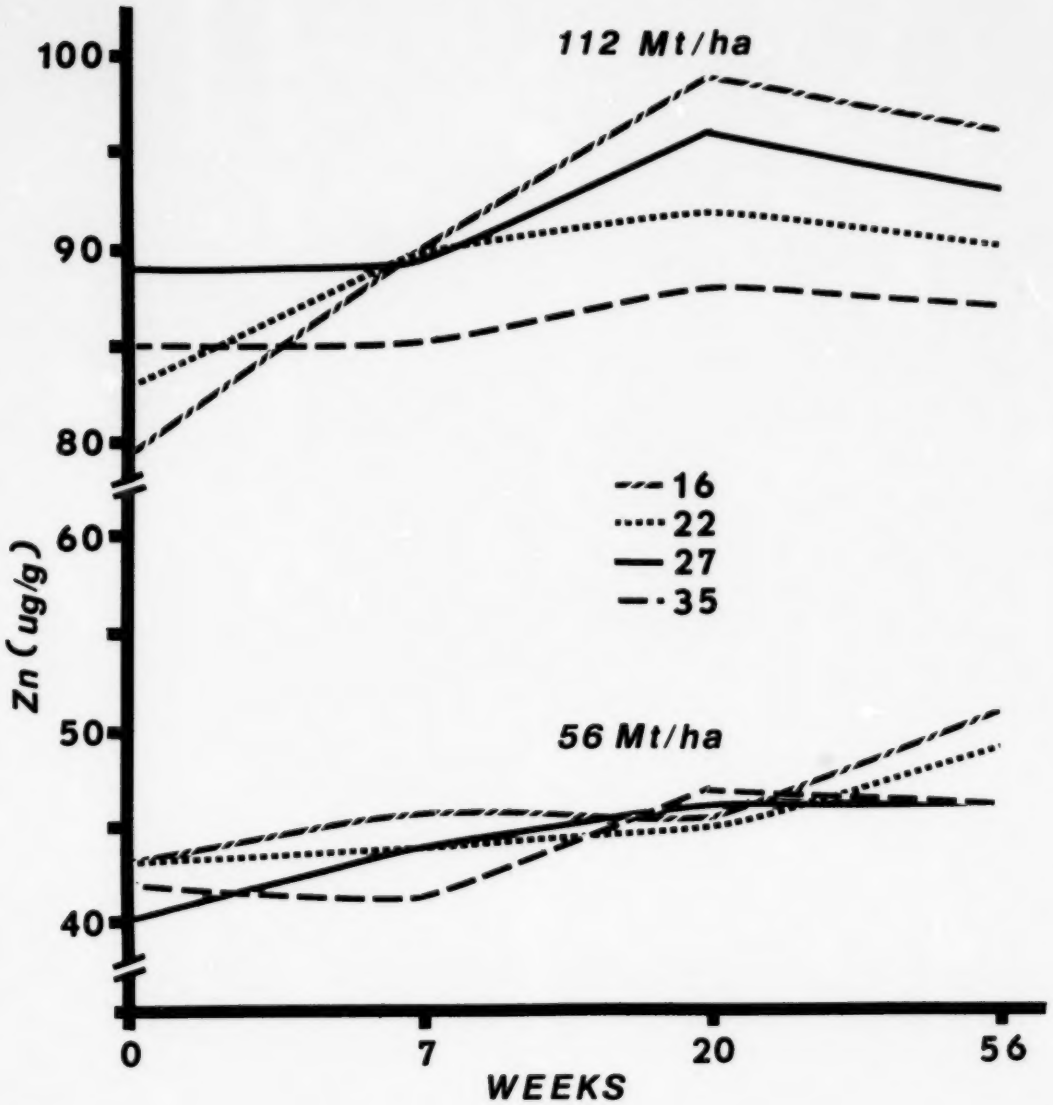

Figure 11. Average DTPA-TEA extractable Zn concentrations at several sampling dates as affected by soil temperature and sewage sludge application at rates of 56 and 112 metric tons/ha.

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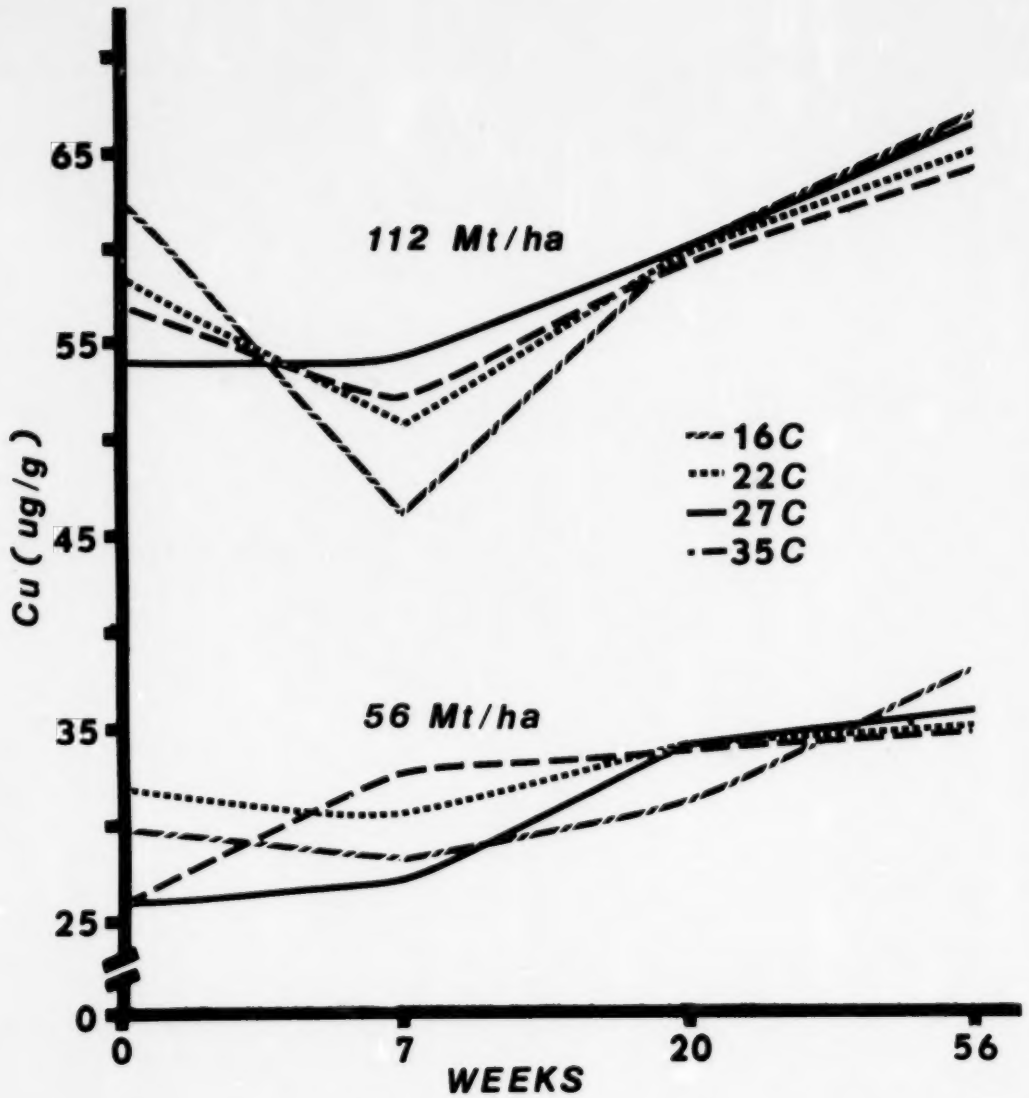

Figure 12. Average DTPA-TEA extractable Cu concentrations at several sampling dates as affected by soil temperature and sewage sludge application at rates of 56 and 112 metric tons/ha.

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at 43°C increased Zn availability and postulated that it was due to decomposition of chelating agents or the solubilizing of Zn in minerals due to an increase in H^+ activity.

A downward movement of Zn and Cu in the soil profile occurred (Tables 20 and 21). As depth increased, concentrations of Zn and Cu decreased but these were higher than the check (0 sludge) concentrations. Cadmium and Ni concentrations at 35 and 61-cm depths were small and did not differ from the check concentration.

At higher sludge application rates, greater movement was noted. A soil temperature of 16°C resulted in significantly higher extractable Zn levels at the 15-cm depth for 112 ton sludge plots, but this was not observed at 25 and 61 cm.

Physical Properties

Bulk density and water stable aggregation were determined for soil samples taken 92 weeks after the start of the experiment. Bulk density decreased and aggregation increased due to sludge application (Tables 22 and 23). Soil temperature had no significant effect on soil physical properties. Epstein (1975) also observed increased aggregation and decreased bulk density due to sewage sludge application.

Pathogen Survival

Initial fecal coliform numbers in the soil amended with sludge at levels of 0, 56, and 112 metric tons/ha were 1.6×10^1, 1.2×10^4, and 2.2×10^4/g dry soil, respectively. Values for the zero sludge rate were generally constant throughout the 91-day study. Fecal coliform numbers in the 56 and 112 metric tons/ha sludge-amended soils exhibited a significant decrease with time under the four temperature regimes studied (Figure 13). A linear relationship existed between log fecal coliforms and time during the 91-day study for the 56 and 112 metric tons/ha sludge levels and all temperature regimes except the 56 metric tons/ha sludge plots maintained at 35°C, where the regression was best described by a quadratic equation. Coefficients of determination were greater than 0.808 except for the ambient termperature plot for both levels of sludge. The temperature of the ambient plots was not held constant and varied between 20 and 24°C.

The time required for a 99.9% reduction in the initial fecal coliform values and the survival rate constant values (K) calculated from the regression equations are presented in Table 24. The survival rate constant is given by equation (1).

$$K = (\log_{10} N_t/N_0)\ (-t^{-1}) \qquad (1)$$

where

K = survival rate constant, $days^{-1}$

N_0 and N_t = bacterial populations at 0 and t days, respectively

t = time in days

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TABLE 20. AVERAGE DTPA-TEA-ZN CONCENTRATIONS AT DEPTHS OF 15, 25, AND 61 CM AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate (metric tons/ha)					
	Soil depth (cm)			Soil depth (cm)		
	15	25	61	15	25	61
C	- - - - - - - - - - - - - µg/g- - - - - - - - - - - - -					
16	106a*	15.9a	2.74a	56a	10.1a	1.11a
22 (ambient)	94b	14.0a	2.32a	48a	5.9a	2.31a
27	97b	12.0a	3.00a	46a	6.0a	1.33a
35	85b	11.0a	2.76a	43a	5.7a	1.24a
Check#	1.30	.68	0.43			

* Means with soil depths followed by same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

\# Check plots values are across all soil temperatures

TABLE 21. AVERAGE DTPA-TEA CU CONCENTRATIONS AT DEPTHS OF 15, 25 AND 61 CM AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate (metric tons/ha)					
	Soil depth (cm)			Soil depth (cm)		
	15	25	61	15	25	61
C	- - - - - - - - - - - - - µg/g- - - - - - - - - - - - -					
16	78a*	12.8a	1.40a	28a	5.64a	.92a
22 (ambient)	70ab	5.9a	1.03a	38a	3.77a	.88a
27	68b	10.6a	1.57a	35a	3.91a	1.15a
35	63c	7.9a	1.94a	36a	3.71a	.67a
Check#	1.20	.80	.60			

* Means with soil depths followed by same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

\# Check plots values are across all soil temperatures.

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TABLE 22. STABLE AGGREGATE LEVELS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION RATE

Temperature	Sludge rate (Mt/ha) 0	56	112	Average
C	- - - - - - - - - - - - - - - % - - - - - - - - - - - - -			
16	22.5c*	65.7b	78.4a	55.6A
22 (ambient)	29.2c	70.1b	84.2a	61.2A
27	28.3c	53.5b	83.0a	54.9A
35	29.0c	57.7b	77.2a	54.6A
Average	27.2C	61.8B	80.7B	

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.
P = .95.

TABLE 23. AVERAGE BULK DENSITY OF SOIL AMENDED WITH THREE RATES OF SEWAGE SLUDGE AND SUBJECTED TO FOUR SOIL TEMPERATURES

Temperature	Sludge rate (Mt/ha) 0	56	112	Average
C	- - - - - - - - - - - - - g/cm^3 - - - - - - - - - - - -			
16	1.62a*	1.40a	1.32a	1.45A
22 (ambient)	1.55a	1.40a	1.34a	1.43A
27	1.52a	1.43a	1.28a	1.41A
35	1.53a	1.36a	1.27a	1.39A
Average	1.56A	1.40B	1.30C	

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.
P = .95.

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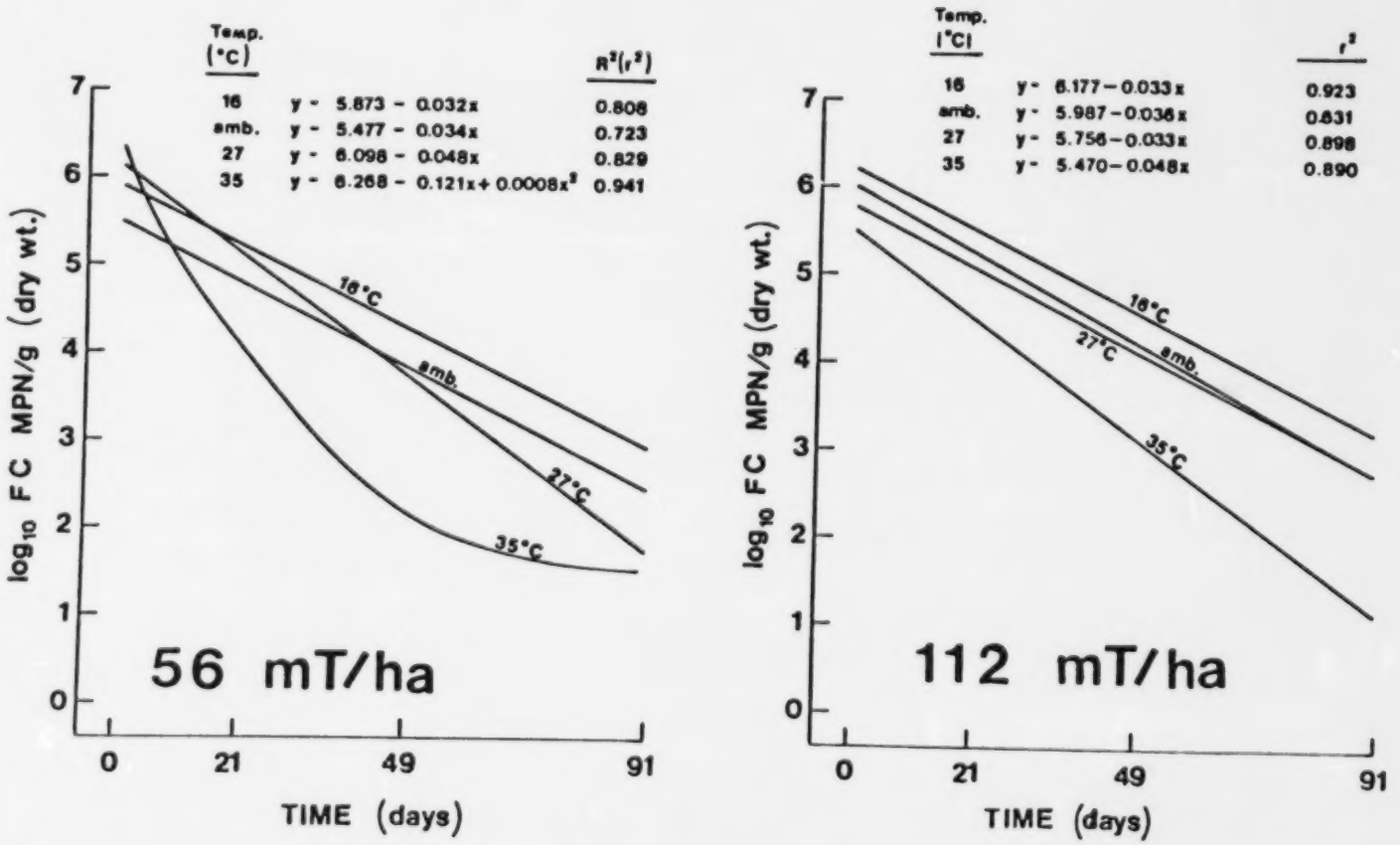

Figure 13. Fecal coliform numbers in a Sassafras sandy loam soil amended with two rates of sewage sludge and maintained under four temperature regimes.

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TABLE 24. THE 99.9% REDUCTION IN TIMES AND SURVIVAL RATE CONSTANTS (K) FOR FECAL COLIFORMS IN A SASSAFRAS SANDY LOAM AMENDED WITH TWO SEWAGE SLUDGE RATES AND MAINTAINED UNDER FOUR TEMPERATURE REGIMES

Sludge treatment	Temperature	99.9% reduction	Survival rate constant (K)*
Mt/ha	°C	days	$days^{-1}$
56	16	92	0.032 ± 0.011
	ambient	90	0.034 ± 0.014
	27	62	0.048 ± 0.015
	35	29	0.081 ± 0.018#
112	16	91	0.033 ± 0.006
	ambient	83	0.036 ± 0.018
	27	91	0.033 ± 0.008
	35	62	0.048 ± 0.012

* K values are listed with ± values required to calculate the 95% confidence interval.

\# The 56 metric tons/ha sludge rate at 35°C K value was calculated for the 0 to 49 day time period.

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Similar time periods of approximately 90 days were required for 99.9% reduction of the initial populations in the 56 metric tons/ha sludge plots maintained at ambient and 16°C and the 112 metric tons/ha sludge plots at 16 and 27°C. Slightly less time was required for 99.9% reduction in the 112 metric tons/ha sludge plots at ambient temperature. The fluctuation of ambient temperature may be the reason for the more rapid reduction in fecal coliform population. Notable differences in fecal coliform survival rate existed between the plots that received 56 and 112 metric tons/ha sludge maintained at 27 and 35°C. At the two highest temperatures, greater persistence of fecal coliforms was observed in the 112 metric tons/ha sludge plots compared to the 56 metric tons/ha plot. Both survival parameters, 99.9% reduction times and survival rate constants, were calculated from the same linear regression equations. The only exception was with the 56 metric tons/ha sludge at 35°C treatment for which the regression equation was determined for the 0 to 49-day time interval because the coefficient of determination value for the 91-day time period was quite low. Not only must the K values be calculated from linear regression equations to fulfill the assumption of exponential die-away, but, the equation must describe a "good fit" (viz., high r^2) of the population change regressed on time if relative survival patterns are to be evaluated.

The survival of fecal streptococci in the Sassafras soil amended with anaerobically digested sewage sludge was influenced by temperature, sludge rate, and time. A linear equation described the relationship of log fecal streptococci and time for the 56 and 112 metric tons/ha levels and temperature except for the 56 metric tons/ha sludge rate at 35°C treatment (Figure 14). This curvilinear relationship may indicate the survival of resistant organisms in the population. Coefficients of determination were greater than 0.874 except for the 27 and 35°C plots amended with 112 metric tons/ha sludge. The levels of fecal streptococci in the control plots averaged approximately 20/g soil during the 91-day study and were not considered in the calculations. At the 56 and 112 metric tons/ha sludge rates, fecal streptococcus numbers generally decreased more rapidly as the temperature regime increased. At the 112 metric tons/ha sludge rate, the time required for 99.9% reduction at ambient, 16, and 27°C was similar to that observed in the 56 metric tons/ha sludge plots at comparable temperatures (Table 25). The relative fecal streptococcus survival at 35°C appeared to be enhanced by the higher loading rate of sludge since the item for 99.9% reduction at the 56 metric tons/ha sludge rate was 41 days compared to 67 days at the highest sludge rate. At both the 56 and 112 metric tons/ha sludge rate, the greatest fecal streptococcus persistence, smallest survival rate constant, occurred at the coolest temperature.

Compared to fecal coliforms, fecal streptococci better survived the prevailing environmental conditions in the 56 metric tons/ha sludge treated soil at all temperature regimes except ambient. The fluctuation in ambient temperature may have affected the fecal streptococci more than the fecal coliforms. Fecal coliforms showed greater persistence than the fecal streptococci in the 112 metric tons/ha plots maintained at ambient and 27°C. Fecal streptococci survived longer at 16 and 35°C. The greatest survival occurred at 16°C and least survival occurred at 35°C for both indicator organisms at both 56 and 112 metric tons/ha sludge rates. Organism survival was enhanced

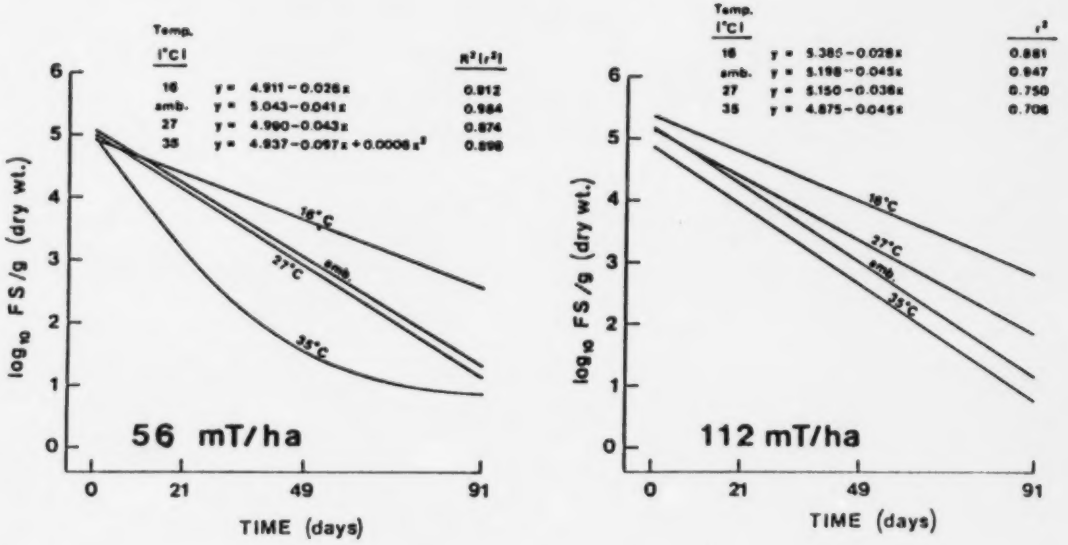

Figure 14. Fecal streptococcus numbers in a Sassafras sandy loam amended with two rates of sewage sludge and maintained under four temperature regimes.

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at the higher temperature regimes of 27 and 35°C by the highest sludge rate.

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TABLE 25. THE 99.9% REDUCTION TIMES AND SURVIVAL RATE CONSTANTS (K) FOR FECAL STREPTOCOCCI IN A SASSAFRAS SANDY LOAM AMENDED WITH TWO SEWAGE SLUDGE RATES AND MAINTAINED UNDER FOUR TEMPERATURE REGIMES

Sludge treatment	Temperature	99.9% reduction	Survival rate constant (K)*
Mt/ha	°C	days	$days^{-1}$
56	16	115	0.026 ± 0.006
	ambient	73	0.041 ± 0.004
	27	70	0.043 ± 0.011
	35	41	0.075 ± 0.015#
112	16	107	0.028 ± 0.007
	ambient	67	0.045 ± 0.007
	27	81	0.037 ± 0.014
	35	67	0.045 ± 0.020

* K values are listed with ± values required to calculate the 95% confidence interval.

\# The 56 metric tons/ha sludge rate at 35°C K value was calculated for the 0 to 49 day time period.

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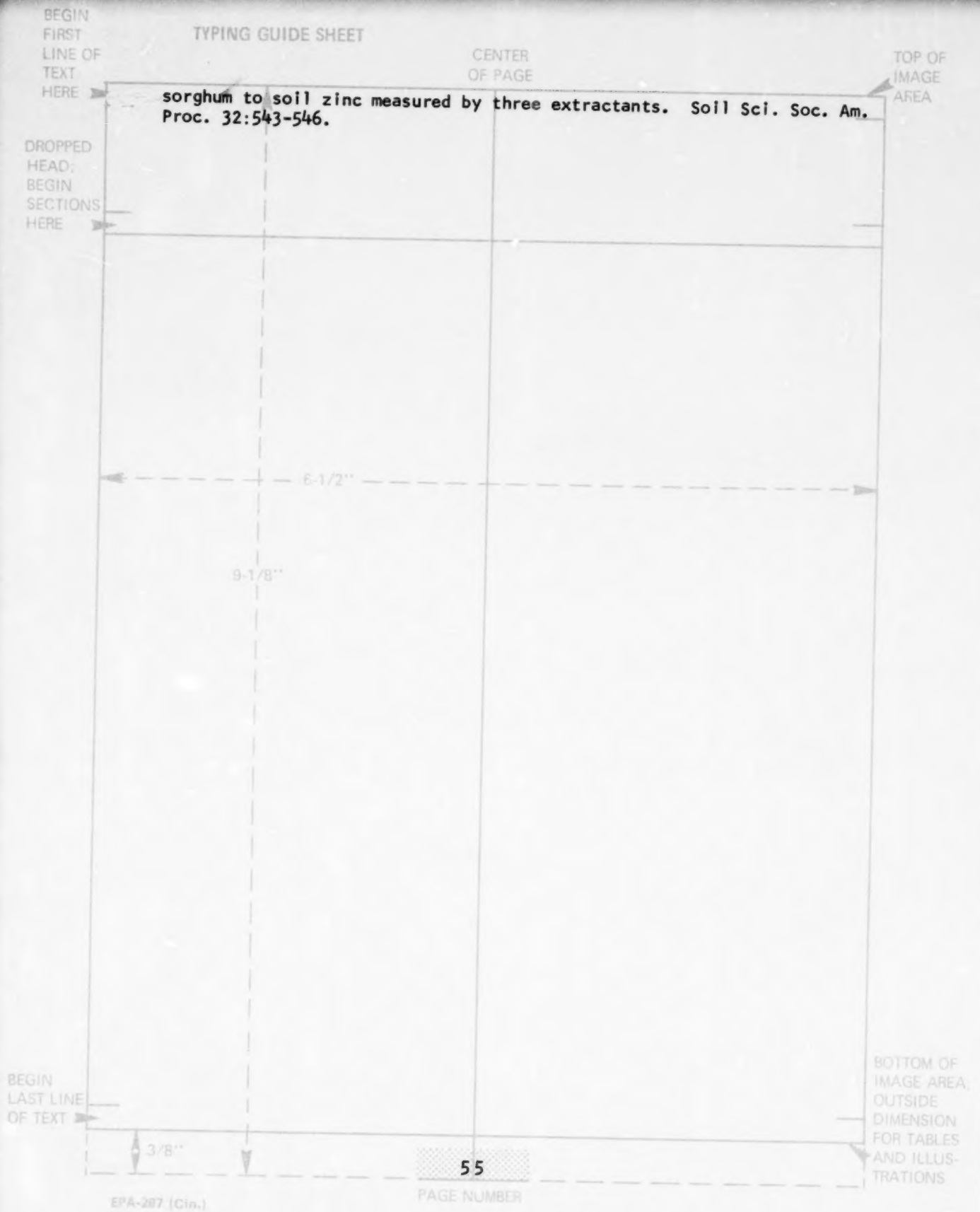
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APPENDIX A

DIAGRAM OF FIELD EQUIPMENT

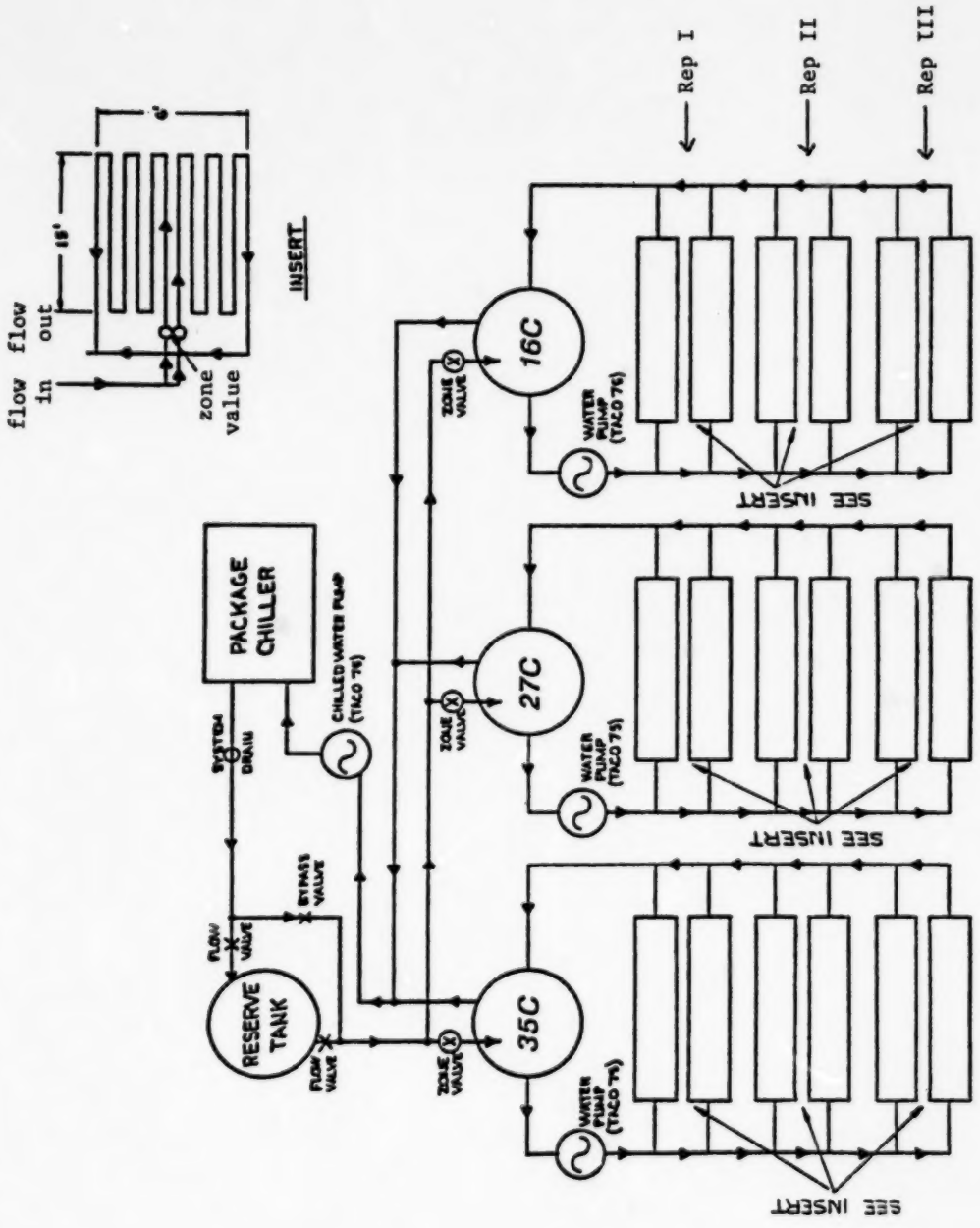

Figure A-1. Diagram of field equipment used for soil temperature regulation (MacLeod and Decker, 1968).

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APPENDIX B

SOIL TEMPERATURES-FIELD EXPERIMENT

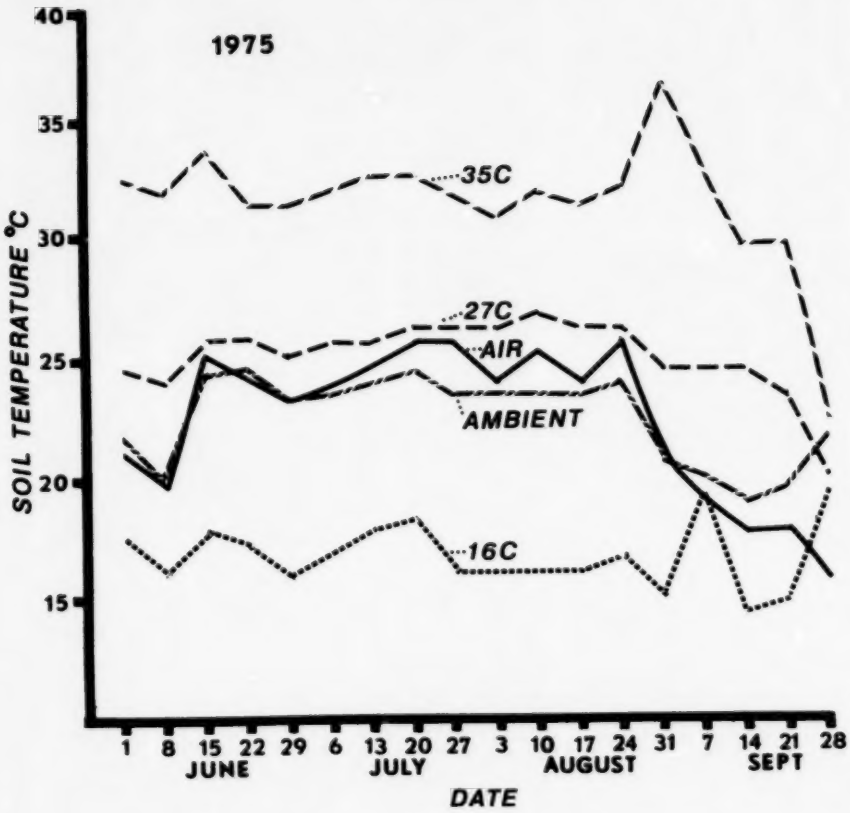

Figure B-1. Soil temperatures taken at a 5-cm depth and at 15 cm air temperature above the soil surface during 1975.

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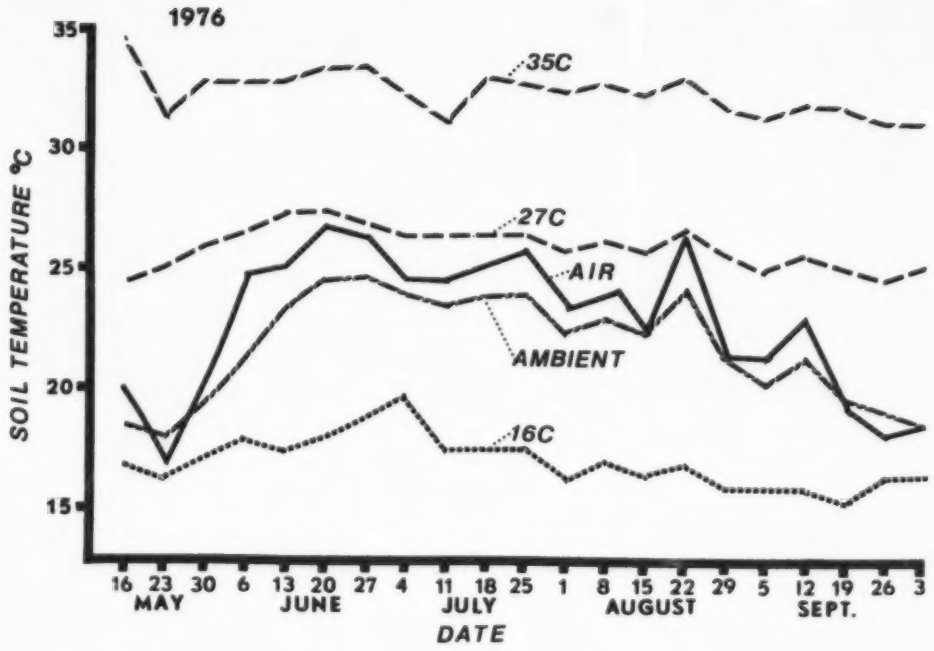

Figure B-2. Soil temperature at a 5 cm depth and at 15 cm air temperature above the soil surface, 1976.

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APPENDIX C

CORN DEVELOPMENT

TABLE C-1. AVERAGE STOVER AND GRAIN YIELDS, LEAF NUMBERS, AND PLANT HEIGHTS FOR MATURE PLANTS AS AFFECTED BY SEWAGE SLUDGE APPLICATION AND SOIL TEMPERATURE. 1975.

Soil temperature	Sludge rate	Stover	Grain	Leaf	Height
°C	Mt/ha	- - g/plant - - -		No.	-m-
16	0	51.3d*	80.7b	11.7a	2.12a
	56	46.6d	94.7b	11.2a	2.17a
	112	59.3cd	115.3a	12.1a	2.30a
	Average	52.7B	96.7B	11.7C	2.20B
22 (Ambient)	0	73.3bc	124.7a	12.4a	2.46a
	56	76.7b	124.7a	12.4a	2.52a
	112	90.0ab	134.0a	12.8a	2.57a
	Average	80.0A	127.8A	12.5B	2.52A
27	0	86.7ab	122.0a	12.6a	2.50a
	56	84.0ab	121.3a	12.6a	2.54a
	112	95.3a	126.7a	12.7a	2.61a
	Average	88.7A	123.3A	12.6B	2.55A
35	0	82.0ab	119.3a	13.5a	2.53a
	56	93.3a	122.0a	13.4a	2.43a
	112	90.7ab	119.3a	13.8a	2.54a
	Average	88.7A	120.0A	13.5A	2.51A
Average	0	73.3B	111.3B	12.5A	2.40A
	56	75.3B	116.0AB	12.4A	2.42A
	112	84.0A	124.0A	12.9A	2.51A
CV		9.84%	6.98%	3.08%	4.79%

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE C-2. AVERAGE STOVER AND GRAIN YIELDS, LEAF NUMBERS, AND PLANT HEIGHTS FOR MATURE PLANTS AS AFFECTED BY SEWAGE SLUDGE APPLICATION AND SOIL TEMPERATURE. 1976

Soil Temperature	Sludge rate	Stover	Grain	Leaf	Height
°C	Mt/ha	- g/plant -		No.	-m-
16	0	36.0f*	50.0f	11.2a	1.74a
	56	44.0ef	88.7de	11.2a	1.76a
	112	40.0ef	90.7de	11.2a	1.79a
	Average	40.0C	76.7C	11.2B	1.77C
22 (Ambient)	0	45.5de	76.7ef	12.0a	1.93a
	56	62.0cd	135.3c	11.7a	2.02a
	112	92.0ab	146.7abc	11.5a	2.05a
	Average	69.3B	119.3B	11.7B	2.00B
27	0	63.3cd	98.7de	13.1a	2.05a
	56	78.6bc	145.3bc	13.0a	2.15a
	112	94.7ab	172.0a	12.0a	2.23a
	Average	79.3AB	138.7A	13.0A	2.15A
35	0	80.7b	90.0d	12.4a	2.11a
	56	96.0ab	156.0ab	12.9a	2.26a
	112	102.0a	176.0a	13.1a	2.27a
	Average	92.7A	143.3A	12.8A	2.21A
Average	0	58.7C	80.7C	12.2A	1.96C
	56	70.0B	131.3B	12.2A	2.05B
	112	82.0A	146.7A	12.2A	2.09A
CV		10.0%	12.0%	2.32%	3.09%

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

APPENDIX D

CORN DEVELOPMENT - EAR LEAF MACRONUTRIENTS

TABLE D-1. AVERAGE N, P, K, MG AND CA CONCENTRATIONS IN CORN EAR LEAVES AS AFFECTED BY SEWAGE SLUDGE APPLICATION AND SOIL TEMPERATURE. 1975

Soil temperature	Sludge rate	Element				
		N	P	K	Mg	Ca
°C	Mt/ha	- - - - - - - - - - % - - - - - - - - - -				
16	0	2.38g*	0.20a	1.96a	0.16d	0.37e
	56	2.68fg	0.29a	1.93a	0.21c	0.55bc
	112	2.74efg	0.27a	1.73a	0.30a	0.72a
	Average	2.60C	0.25B	1.87B	0.23A	0.55A
22 (Ambient)	0	3.03bc	0.33a	2.20a	0.21cd	0.42de
	56	2.88def	0.41a	2.31a	0.24bc	0.49cde
	112	3.00bc	0.36a	2.01a	0.27ab	0.62ab
	Average	2.97B	0.37A	2.17A	0.24A	0.51B
27	0	3.24ab	0.38a	2.26a	0.20c	0.43cde
	56	3.01bcd	0.44a	2.33a	0.23c	0.41de
	112	3.14abcd	0.38a	2.10a	0.20c	0.48cd
	Average	3.13AB	0.40A	2.23A	0.21AB	0.44C
35	0	2.97cde	0.41a	2.60a	0.18d	0.44cde
	56	3.20abc	0.39a	2.34a	0.17d	0.47cde
	112	3.33a	0.41a	2.20a	0.20c	0.52bcd
	Average	3.16A	0.40A	2.38A	0.18B	0.48BC
Average	0	2.90B	0.33C	2.25A	0.19C	0.41C
	56	2.94AB	0.38A	2.23A	0.21B	0.48B
	112	3.05A	0.35B	2.01B	0.24A	0.58B

* Values within a given element followed by the same letter are not statistically different at the .05 level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE D-2. AVERAGE N, P, K, MG AND CA CONCENTRATIONS IN CORN EAR LEAVES AS AFFECTED BY SEWAGE SLUDGE APPLICATION AND SOIL TEMPERATURE. 1976

Soil temperature	Sludge rate	Element				
		N	P	K	Mg	Ca
°C	Mt/ha	- - - - - - - - - % - - - - - - - - -				
16	0	2.17a*	0.26a	1.84a	0.15a	0.33a
	56	2.07a	0.42a	1.77a	0.19a	0.46a
	112	2.13a	0.35a	1.45a	0.22a	0.54a
	Average	2.12A	0.34B	1.68BC	0.18D	0.44A
22 (Ambient)	0	1.77a	0.37a	1.53a	0.23a	0.33a
	56	2.40a	0.60a	1.63a	0.27a	0.39a
	112	2.83a	0.52a	1.50a	0.27a	0.46a
	Average	2.33A	0.50A	1.55C	0.26B	0.40B
27	0	1.88a	0.37a	1.74a	0.25a	0.32a
	56	2.47a	0.59a	1.80a	0.28a	0.41a
	112	2.83a	0.40a	1.69a	0.29a	0.48a
	Average	2.39A	0.45A	1.74B	0.28A	0.40B
35	0	2.03a	0.37a	1.98a	0.23a	0.34a
	56	2.40a	0.45a	2.05a	0.23a	0.38a
	112	2.63a	0.47a	2.10a	0.23a	0.48a
	Average	2.36A	0.43A	2.04A	0.23C	0.40B
Average	0	1.96C	0.34C	1.77A	0.22B	0.33C
	56	2.33B	0.51A	1.81A	0.24A	0.41B
	112	2.61A	0.43B	1.68A	0.25A	0.49A

* Values within a given element followed by the same letter are not statistically different at the .05 level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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APPENDIX E

PLANT HEAVY METALS - CORN

TABLE E-1. AVERAGE ZN, CU, CD, NI, AND PB CONCENTRATIONS OF 8.5-LEAF SEEDLINGS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1975

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Cd	Ni	Pb
C	Mt/ha	- - - - - - - - - -		ppm	- - - - - - - - - -	
16	0	42c*	3.6f	0.51a	1.57a	0.95a
	56	293b	10.5e	0.90a	1.50a	0.86a
	112	331b	11.6de	0.82a	1.77a	0.88a
	Average	222B	8.6B	0.74C	1.61A	0.90B
22 (Ambient)	0	67c	5.8f	0.71a	1.14a	1.09a
	56	312b	14.2cd	1.10a	1.64a	0.88a
	112	378a	16.8ab	0.77a	2.59a	0.93a
	Average	253B	12.3A	0.86B	1.78A	0.97B
27	0	68c	5.5f	0.60a	1.42a	1.00a
	56	289b	11.5de	0.95a	1.46a	0.72a
	112	389a	17.3a	0.78a	2.19a	1.18a
	Average	248B	11.4A	0.76C	1.69A	0.97B
35	0	86c	7.2f	0.85a	0.90a	1.22a
	56	405a	13.5c	1.40a	1.65a	1.12a
	112	411a	14.9bc	1.06a	2.02a	2.06a
	Average	300A	11.9A	1.10A	1.57A	1.46A
Average	0	65Z	5.5Z	0.67Z	1.26Y	1.06X
	56	325Y	12.4Y	1.09X	1.56XY	0.89X
	112	377X	15.1X	0.86Y	2.14X	1.26X

* Means within each metal followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-2. AVERAGE ZN, CU, CD, NI, AND PB CONCENTRATIONS OF 8.5-LEAF SEEDLINGS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1976

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Cd	Ni	Pb
C	Mt/ha	ppm				
16	0	27e*	5.5c	0.46a	0.70a	0.70a
	56	229d	5.4c	0.95a	1.05a	0.70a
	112	335b	8.8b	0.89a	1.54a	2.19a
	Average	197C	6.5B	0.76B	1.10A	1.20A
22 (Ambient)	0	36e	5.1c	0.24a	0.70a	0.92a
	56	221d	7.0b	0.76a	1.10a	0.78a
	112	330b	7.9b	1.07a	2.28a	0.74a
	Average	196C	6.7B	0.69B	1.36A	0.84A
27	0	47e	7.8b	0.34a	0.58a	0.62a
	56	273c	12.7a	1.14a	1.31a	0.60a
	112	288bc	15.2a	1.06a	1.81a	0.42a
	Average	236B	11.9A	0.85AB	1.24A	0.55A
35	0	65e	7.8b	0.61a	0.62a	0.76a
	56	289bc	12.9a	1.17a	1.11a	0.67a
	112	432a	12.6a	1.28a	1.80a	0.68a
	Aaverage	262A	11.1A	1.02A	1.18A	0.77A
Average	0	44Z	6.6Z	0.41Y	0.65Z	0.75X
	56	253Y	9.5Y	1.00X	1.14Y	0.69X
	112	371X	11.1X	1.07X	1.86X	1.01X

* Means within each metal followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-3. AVERAGE ZN, CU, CD, NI, AND PB CONCENTRATIONS OF CORN EAR LEAVES AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1975

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Cd	Ni	Pb
C	Mt/ha	- - - - - - - - - - -ppm - - - - - - - - - -				
16	0	21f*	4.2e	0.10a	0.36a	2.23a
	56	95e	10.8c	0.36a	0.49a	1.67a
	112	159bc	13.7a	0.36a	0.64a	1.75a
	Average	92D	9.6A	0.09B	0.49A	1.88B
22 (Ambient)	0	30f	8.4d	0.05a	0.34a	2.89a
	56	125de	9.9cd	0.49a	0.54a	2.46a
	112	170b	11.4abc	0.50a	1.07a	2.83a
	Average	109C	9.9A	0.34A	0.65A	2.72A
27	0	33f	10.3cd	0.06a	0.39a	2.06a
	56	145cd	9.9cd	0.53a	0.56a	1.93a
	112	183b	11.1bc	0.50a	0.48a	2.01a
	Average	120B	10.4A	0.36A	0.48A	2.00B
35	0	39f	9.5cd	0.09a	0.35a	2.21a
	56	174b	9.9cd	0.44a	0.42a	1.88a
	112	217a	13.2ab	0.46a	0.71a	1.90a
	Average	143A	10.9A	0.33A	0.49A	2.00B
Average	0	31C	8.1C	0.08B	0.36B	2.34A
	56	135B	10.1B	0.45A	0.50AB	1.98B
	112	183A	12.3A	0.45A	0.72A	2.12A

* Means within a given element followed by the same letter are not statistically different at the .05 level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-4. AVERAGE ZN, CU, CD, NI, AND PB CONCENTRATIONS OF CORN EAR LEAVES AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1976

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Cd	Ni	Pb
C	Mt/ha	- - - - - - - - - - ppm - - - - - - - - - -				
16	0	18f*	6.2de	0.13a	0.58a	3.01a
	56	73e	5.9de	0.35a	0.64a	2.31a
	112	104d	8.1cd	0.33a	0.54a	2.33a
	Average	65C	6.7B	0.27B	0.59B	2.49A
22 (Ambient)	0	27f	5.4e	0.21a	1.08a	1.91a
	56	109d	7.1de	0.43a	1.47a	1.17a
	112	144c	8.0cd	0.44a	1.83a	1.11a
	Average	93B	6.8B	0.36B	1.46A	2.37A
27	0	22f	5.0e	0.25a	1.09a	0.96a
	56	113cd	9.6bc	0.36a	1.02a	1.09a
	112	206a	12.3ab	0.36a	1.53a	1.14a
	Average	113A	9.0A	0.32B	1.21AB	2.67A
35	0	26f	6.2de	0.39a	0.73a	1.62a
	56	137c	11.0ab	0.60a	0.96a	1.30a
	112	180b	11.8ab	0.66a	1.15a	1.51a
	Average	114A	9.7A	0.55A	0.95AB	2.61A
Average	0	23C	5.7B	0.25B	0.87B	1.88A
	56	108B	8.4AB	0.44A	1.02AB	1.47AB
	112	158A	10.1A	0.45A	1.26A	1.52B

* Values within a given element followed by the same letter are not statistically different at the .05 level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-5. AVERAGE ZN CONCENTRATIONS IN STOVER AND GRAIN IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Year 1975 Grain	Year 1975 Stover	Year 1976 Grain	Year 1976 Stover
C	Mt/ha	- - - - - - - - - - ppm - - - - - - - - - -			
16	0	15f*	13e	19d	19d
	56	35d	193d	32b	237a
	112	35d	333ab	36ab	312a
	Average	28D	180B	29A	189B
22 (Ambient)	0	18e	9e	27c	44c
	56	37c	193d	37ab	258a
	112	41c	286bc	40a	291a
	Average	32C	163B	35A	198A
27	0	20e	13e	25cd	57c
	56	40c	216cd	31b	216b
	112	47a	274bc	40a	320a
	Average	36B	168B	32A	198A
35	0	21e	20e	27c	47c
	56	46b	285bc	37ab	197b
	112	51a	371a	37ab	233a
	Average	40A	226A	33A	159A
Average	0	18C	14C	24C	42C
	56	40B	222B	34B	227B
	112	44A	316A	38A	289A

* Values within each plant category followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-6. AVERAGE CU CONCENTRATIONS IN STOVER AND GRAIN IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Year 1975 Grain	1975 Stover	1976 Grain	1976 Stover
C	Mt/ha	ppm			
16	0	1.66a*	3.34d	1.61a	3.01a
	56	1.94a	6.11c	1.62a	4.75a
	112	1.83a	9.31ab	1.73a	4.06a
	Average	1.81B	6.25B	1.65A	3.94A
22 (Ambient)	0	1.08a	7.29c	1.60a	3.77a
	56	1.67a	7.60c	1.80a	4.89a
	112	1.60a	9.58ab	1.77a	3.57a
	Average	1.45A	8.14A	1.72A	4.08A
27	0	1.65a	8.07b	1.63a	4.47a
	56	1.85a	7.61c	1.77a	5.09a
	112	1.81a	10.09a	1.62a	4.31a
	Average	1.77A	8.59A	1.64A	4.62A
35	0	1.64a	6.99c	1.55a	4.94a
	56	2.03a	8.72ab	1.95a	4.56a
	112	2.05a	9.42ab	1.88a	4.35a
	Average	1.91A	8.40A	1.70A	4.62A
Average	0	1.51C	6.43C	1.65A	4.05A
	56	1.87A	7.50B	1.72A	4.83A
	112	1.82B	9.59A	1.64A	4.08A

* Values within each plant category followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE E-7. AVERAGE CD CONCENTRATIONS IN STOVER AND GRAIN IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Year 1975 Grain	Year 1975 Stover	Year 1976 Grain	Year 1976 Stover
C	Mt/ha	ppm			
16	0	0.05e*	0.37c	0.05a	0.18c
	56	0.12ab	1.57a	0.10a	0.36b
	112	0.09bcd	1.33a	0.10a	0.55ab
	Average	0.09AB	1.09B	0.09A	0.36A
22 (Ambient)	0	0.04e	0.24c	0.07a	0.46a
	56	0.09bcd	0.97a	0.10a	0.78a
	112	0.11ab	0.77b	0.12a	0.44b
	Average	0.08AB	0.66A	0.09A	0.56A
27	0	0.04e	0.42c	0.04a	0.31b
	56	0.08cd	0.77b	0.09a	0.61ab
	112	0.12ab	0.96ab	0.07a	0.32b
	Average	0.07B	0.72A	0.07B	0.41A
35	0	0.06de	0.43c	0.06a	0.41b
	56	0.10bc	0.98ab	0.07a	0.59ab
	112	0.15a	1.16a	0.10a	0.38b
	Average	0.10A	0.86A	0.07B	0.46A
Average	0	0.05B	0.37B	0.06B	0.34B
	56	0.10A	1.07A	0.09A	0.59A
	112	0.12A	1.05A	0.10A	0.42B

* Values within each plant category followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE E-8. AVERAGE NI CONCENTRATIONS IN STOVER AND GRAIN IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Year			
		Grain	Stover	Grain	Stover
C	Mt/ha	ppm			
16	0	0.44a*	0.30a	0.28a	0.61a
	56	1.04a	0.55a	0.83a	0.67a
	112	1.72a	0.50a	1.29a	0.96a
	Average	1.07A	0.45A	0.79B	0.74A
22 (Ambient)	0	0.22a	1.43a	0.53a	0.61a
	56	0.92a	2.18a	0.89a	0.93a
	112	1.90a	1.17a	0.99a	0.63a
	Average	1.01A	1.59A	0.80B	0.72A
27	0	0.25a	0.45a	0.40a	0.48a
	56	0.95a	1.07a	0.78a	0.87a
	112	1.36a	0.75a	0.95a	0.58a
	Average	0.85A	0.76A	0.71B	0.64A
35	0	0.25a	0.76a	0.71a	0.61a
	56	0.89a	0.28a	0.87a	0.13a
	112	1.46a	0.48a	1.43a	0.62a
	Average	0.87A	0.84A	1.00A	0.79A
Average	0	0.29C	0.74A	0.48C	0.57B
	56	0.95B	1.27A	0.84B	0.90A
	112	1.61A	0.72A	1.16A	0.69B

* Values within each plant category followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE E-9. AVERAGE PB CONCENTRATIONS IN STOVER AND GRAIN IN 1975 AND 1976 AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Year 1975 Grain	Year 1975 Stover	Year 1976 Grain	Year 1976 Stover
C	Mt/ha	ppm			
16	0	0.09a*	2.23a	0.08a	2.67a
	56	0.06a	1.67a	0.10a	2.56a
	112	0.10a	1.75a	0.91a	2.24a
	Average	0.08A	1.88B	0.10A	2.49A
22 (Ambient)	0	0.12a	2.89a	0.04a	2.61a
	56	0.09a	2.46a	0.08a	2.65a
	112	0.17a	2.83a	0.06a	1.85a
	Average	0.12A	2.72A	0.06B	2.37A
27	0	0.04a	2.06a	0.08a	3.60a
	56	0.06a	1.93a	0.13a	2.71a
	112	0.99a	2.01a	0.06a	1.70a
	Average	0.07A	2.00B	0.09A	2.67A
35	0	0.24a	2.21a	0.04a	2.10a
	56	0.08a	1.88a	0.05a	2.13a
	112	0.05a	1.90a	0.09a	1.62a
	Average	0.12A	2.00B	0.06B	2.61A
Average	0	0.12A	2.34A	0.06A	3.21A
	56	0.07A	1.98A	0.09A	2.50AB
	112	0.10A	2.12A	0.08A	1.91B

* Values within each plant category followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

APPENDIX F

PLANT HEAVY METALS - RADISHES

TABLE F-1. AVERAGE ZN, CU, NI, CD, AND PB LEVELS IN RADISH ROOTS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1975

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Ni	Cd	Pb
C	Mt/ha	---------- ppm ----------				
16	0	56cd*	5.0f	1.32d	0.64cd	4.16a
	56	368b	15.8bcde	6.56ab	0.84cd	9.38a
	112	362b	17.9bc	7.99ab	0.73cd	8.47a
	Average	263B	12.9B	5.29A	0.74B	7.34A
22 (Ambient)	0	58d	4.9f	2.75d	0.60cd	9.07a
	56	197bc	6.9cd	5.25bc	0.59cd	2.90a
	112	302b	16.4bcd	7.15ab	0.89cd	5.56a
	Average	186C	9.4B	5.05A	0.70B	5.84A
27	0	98cd	5.8ef	3.69bcd	0.49d	3.75a
	56	231bc	2.9f	4.02bcd	0.96cd	5.52a
	112	405b	25.5b	7.56ab	1.16c	5.58a
	Average	245B	11.4B	5.09A	0.87B	4.95A
35	0	79d	8.3cdef	3.19cd	1.06c	3.98a
	56	371b	17.1bc	6.55ab	1.69b	3.60a
	112	704a	59.2a	10.30a	2.73a	8.41a
	Average	385A	28.2A	6.68A	1.83A	5.33A
Average	0	73C	6.0C	2.7C	0.70C	7.01A
	56	292B	10.7B	5.6B	1.02B	5.35A
	112	443A	29.7A	8.3A	1.38A	7.01A

* Values for metals followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE F-2. AVERAGE ZN, CU, NI, CD, AND PB LEVELS IN RADISH TOPS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1975

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Ni	Cd	Pb
C	Mt/ha	- - - - - - - - - ppm - - - - - - - - -				
16	0	69e*	11.0ef	3.58c	1.09a	7.27a
	56	587bc	22.8cd	9.84b	1.20a	4.74a
	112	569bc	23.2cd	9.80b	1.32a	6.38a
	Average	408A	19.0B	7.74C	1.20BC	6.13A
22 (Ambient)	0	64e	9.8ef	1.15c	0.97a	5.05a
	56	295de	16.6de	5.01c	1.10a	5.68a
	112	663bc	36.1b	10.14b	1.78a	4.22a
	Average	341A	21.8B	5.44B	1.29C	4.98A
27	0	68e	10.9ef	2.08c	1.17a	6.87a
	56	382cd	12.5ef	4.85c	1.14a	3.74a
	112	772b	36.1b	10.33b	2.12a	4.33a
	Average	431A	19.8B	5.75BC	1.48B	4.98A
35	0	86e	6.8f	2.23c	2.13a	4.00a
	56	490cd	26.9c	9.25b	2.76a	3.25a
	112	1071a	59.9a	19.77a	2.63a	7.05a
	Average	551A	31.2A	10.51A	2.84A	4.77A
Average	0	89C	9.6C	2.3C	1.34B	5.8A
	56	439B	19.7B	7.3B	1.55B	4.4A
	112	770A	39.6A	12.5A	2.21A	5.5A

* Values for metals followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE F-3. AVERAGE ZN, CU, NI, CD, AND PB LEVELS IN RADISH ROOTS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1976

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Ni	Cd	Pb
C	Mt/ha	ppm				
16	0	54e*	4.6c	9.3a	0.62a	10.5a
	56	207cd	9.4ab	7.4a	0.51a	7.5a
	112	281ab	9.5ab	12.0a	0.48a	8.4a
	Average	181A	7.8A	9.5A	0.54B	8.8A
22 (Ambient)	0	57e	4.6c	4.2a	0.62a	11.4a
	56	229bcd	7.8bc	4.5a	0.65a	3.3b
	112	284ab	9.6ab	7.9a	0.48a	4.6b
	Average	189A	7.3A	5.6A	0.59B	6.4BC
27	0	46e	8.0bc	4.0a	0.65a	3.3b
	56	196d	7.1b	5.9a	0.51a	2.8b
	112	269abc	8.7bc	6.9a	0.54a	7.5a
	Average	170A	7.9A	5.8A	0.57B	4.5C
35	0	61e	3.6c	2.6a	0.64a	3.4b
	56	249bcd	9.8ab	6.6a	0.72a	3.9b
	112	333a	13.9a	9.2a	1.06a	3.7b
	Average	214A	9.2A	6.2A	0.81A	3.7C
Average	0	54C	5.2C	5.1B	0.63A	7.2A
	56	220B	8.5B	6.1B	0.60A	4.4B
	112	292A	10.4A	9.0A	0.64A	6.0AB

* Values for metals followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE F-4. AVERAGE ZN, CU, NI, CD, AND PB LEVELS IN RADISH TOPS AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION. 1976

Soil temperature	Sludge rate	Metals				
		Zn	Cu	Ni	Cd	Pb
C	Mt/ha	ppm				
16	0	54d*	5.9cd	1.36a	0.85a	1.92a
	56	387b	9.5bc	4.11a	1.02a	2.23a
	112	532a	11.5b	6.02a	1.02a	2.83a
	Average	324A	9.0A	3.83A	0.96A	2.33A
22 (Ambient)	0	57d	6.4cd	1.55a	0.92a	1.45a
	56	375b	9.1bc	4.15a	1.08a	2.95a
	112	518a	13.8b	6.76a	1.11a	2.85a
	Average	317A	9.8A	4.15A	1.04A	2.42A
27	0	53d	6.5cd	1.27a	1.04a	2.60a
	56	290c	9.2bc	2.86a	0.87a	2.55a
	112	388b	9.9bc	6.17a	0.91a	2.40a
	Average	244B	8.5A	3.43A	0.94A	2.51A
35	0	83d	4.5d	1.66a	1.02a	2.49a
	56	339b	11.3bc	5.81a	0.98a	2.54a
	112	482a	21.3a	8.28a	2.33a	2.15a
	Average	301A	12.3A	5.25A	1.44A	2.40A
Average	0	61C	5.8C	1.5C	0.95A	2.1A
	56	348B	9.8B	4.2B	1.00A	2.6A
	112	480A	14.1A	6.8A	1.34A	2.6A

* Values for metals followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test. Capital letters denote main effects.

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APPENDIX G

SOILS

TABLE G-1. AVERAGE PH, MG, P, AND K LEVELS IN SOIL SAMPLED ON 5-20-75 (TIME = 0) AS AFFECTED BY SOIL TEMPERATURE AND SLUDGE APPLICATION

Soil temperature	Sludge rate	pH	Mg	P	K
C	Mt/ha		- - - -	Kg/ha	- - - -
16	0	5.5a*	183a	205a	181a
	56	6.0a	297a	440a	184a
	112	6.3a	355a	575a	174a
	Average	5.9A	278A	407A	179A
22 (Ambient)	0	5.3a	123a	84a	151a
	56	6.0a	305a	446a	185a
	112	6.2a	336a	570a	178a
	Average	5.8A	254A	367A	172A
27	0	5.6a	189a	197a	174a
	56	6.0a	306a	444a	185a
	112	6.2a	330a	583a	176a
	Average	5.9A	276A	408A	178A
35	0	5.6a	192a	250a	163a
	56	6.0a	301a	432a	186a
	112	5.9a	263a	418a	168a
	Average	5.8A	252A	367A	172A
Average	0	5.5B	171B	184C	166B
	56	6.0A	302A	441B	185A
	112	6.2A	321A	537A	174B

* Values within columns followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE G-2. AVERAGE PH, MG, P, AND K LEVELS IN SOIL SAMPLED ON 10-14-75 (20 WEEKS) AS AFFECTED BY SOIL TEMPERATURE AND SLUDGE APPLICATION

Soil temperature	Sludge rate	pH	Mg	P	K
C	Mt/ha		- - - -	Kg/ha	- - - -
16	0	5.4a*	91a	68a	106a
	56	5.8a	164a	267a	90a
	112	5.8a	186a	394a	69a
	Average	5.6A	147A	243A	88A
22 (Ambient)	0	5.4a	95a	71a	69a
	56	5.8a	148a	267a	93a
	112	5.9a	168a	358a	62a
	Average	5.7A	137A	232A	74A
27	0	5.4a	91a	60a	87a
	56	5.8a	156a	244a	80a
	112	5.8a	170a	349a	78a
	Average	5.6A	139A	218A	82A
35	0	5.5a	114a	170a	83a
	56	5.7a	140a	263a	93a
	112	5.7a	136a	245a	75a
	Average	5.6A	130A	226A	93A
Average	0	5.4B	97B	92C	86B
	56	5.8A	152A	260B	94A
	112	5.8A	165A	336A	71C

* Values within columns followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-3. AVERAGE PH, MG, P, AND K LEVELS IN SOIL SAMPLED ON 7-16-76 (56 WEEKS) AS AFFECTED BY SOIL TEMPERATURE AND SLUDGE APPLICATION

Soil temperature	Sludge rate	pH	Mg	P	K
C	Mt/ha		- - - -	Kg/ha	- - - -
16	0	5.2b*	95e	86d	149a
	56	5.8a	172bc	317c	172a
	112	5.8a	208a	457a	197a
	Average	5.6A	159A	288A	172A
22 (Ambient)	0	5.4b	91e	80d	115a
	56	5.7a	178bc	308c	112a
	112	5.8a	188b	414ab	102a
	Average	5.6A	152AB	268AB	110B
27	0	5.3b	95e	78d	100a
	56	5.6a	160cd	282c	85a
	112	5.6a	178bc	414ab	106a
	Average	5.5A	144BC	258AB	96B
35	0	5.4b	99e	77d	106a
	56	5.5a	152d	276c	110a
	112	5.7a	171bcd	400b	112a
	Average	5.6A	141C	251B	110B
Average	0	5.3B	95C	81C	118A
	56	5.7A	166B	295B	121A
	112	5.7A	186A	422A	130A

* Values within columns followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-4. AVERAGE PH, MG, P, AND K LEVELS IN SOIL SAMPLED ON 10-11-76 (68 WEEKS) AS AFFECTED BY SOIL TEMPERATURE AND SLUDGE APPLICATION

Soil temperature	Sludge rate	pH	Mg	P	K
C	Mt/ha		- - - -	g/ha	- - - -
16	0	5.3*	95a	86a	137a
	56	5.7a	172a	312a	155a
	112	5.8a	199a	457a	131a
	Average	5.6A	156A	284A	140A
22 (Ambient)	0	5.3a	99a	80a	110a
	56	5.7a	160a	300a	76a
	112	5. a	155a	400a	95a
	Average	5.5AB	138BC	260AB	92B
27	0	5.1a	94a	76a	77a
	56	5.6a	147a	269a	102a
	112	5.5	152a	403a	77a
	Average	5.4BC	131C	249B	90B
35	0	5.0	113a	76a	95a
	56	5.4	155a	274a	94a
	112	5.4	172a	352a	97a
	Average	5.3C	147AB	234B	101B
Average	0	5.2B	100B	80C	113A
	56	5.6A	159A	288B	104A
	112	5.6A	170A	403A	100A

* Values within columns followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-5. AVERAGE SOIL ORGANIC MATTER OVER TIME AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Sampling times in weeks following sludge application							
		0	3	7	12	20	40	56	68
C	Mt/ha	- % -							
16	0	1.36	1.38	1.22	1.31	1.31	1.26	1.29	1.31
	56	2.42	2.32	2.38	2.18	2.20	2.14	2.19	2.17
	112	3.28	3.28	2.79	2.89	2.84	3.01	3.00	2.95
	Average	2.35a*	2.33a	2.13a	2.12a	2.11a	2.22a	2.16a	2.14a
22 (Ambient)	0	1.28	1.35	1.27	1.34	1.33	1.12	1.28	1.24
	56	2.28	2.58	2.31	2.12	2.17	2.05	2.15	2.11
	112	3.17	3.30	2.78	2.52	2.97	2.90	2.76	2.82
	Average	2.24a	2.41a	2.11a	2.00a	2.16a	1.91a	2.06a	2.06a
27	0	1.35	1.39	1.24	1.33	1.27	1.18	1.32	1.23
	56	2.25	2.22	2.38	2.08	1.78	2.04	2.10	2.13
	112	3.22	3.14	2.37	2.81	2.75	2.89	2.82	2.54
	Average	2.27a	2.25a	2.00a	2.07a	1.93a	2.04a	2.08a	1.96a
35	0	1.33	1.30	1.20	1.24	1.27	1.11	1.25	1.20
	56	2.20	2.37	2.23	2.09	2.12	1.90	2.00	2.01
	112	3.14	3.08	2.50	2.60	2.81	2.88	2.80	2.87
	Average	2.22a	2.25a	1.98a	1.98a	2.07a	1.86a	2.02a	2.01a
Average	0	1.33H	1.36H	1.23I	1.31HI	1.30HI	1.16I	1.29I	1.25I
	56	2.29F	2.37E	2.33EF	2.12C	2.07G	2.03G	2.11G	2.10G
	112	3.20A	3.20A	2.61D	2.70D	2.84B	2.80BC	2.84B	2.78C
	Average	2.27B	2.31A	2.05C	2.04C	2.07C	2.00C	2.08C	2.04C

(Continued)

TABLE G-5 (Continued)

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-6. AVERAGE DTPA-TEA EXTRACTABLE CU CONCENTRATIONS OVER TIME AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Sampling times in weeks following sludge application							
		0	3	7	12	20	40	56	68
C	Mt/ha	ppm							
16	0	.59	.47	.65	.46	.75	.86	.95	1.02
	56	30	37	28	30	31	36	38	37
	112	63	66	46	54	60	69	67	69
	Average	31b-f*	34abc	25f	28def	31b-f	39a	35abc	36ab
22 (Ambient)	0	.56	.50	.64	.81	.74	.94	.83	.89
	56	32	36	30	32	34	37	35	37
	112	58	48	51	50	60	71	65	69
	Average	30b-f	28de	27df	27def	32bcd	32bcde	34bcd	36ab
27	0	.58	.51	.49	.47	.64	.90	.91	.98
	56	30	33	33	32	33	36	35	35
	112	54	72	54	54	60	66	67	67
	Average	28def	35abc	29cdf	29c-f	31bf	34abcd	34ab	34a-d
35	0	.60	.51	.76	.55	.59	.86	.85	.95
	56	26	33	27	37	34	35	35	33
	112	57	58	52	51	57	65	64	60
	Average	28def	30b-f	27ef	29cf	31bf	34abcd	33bcd	31ad
Average	0	.59G	.50G	.63G	.57G	.68G	.89G	.88G	.96G
	56	29F	34D	30DF	33DE	33DE	36D	36D	35D
	112	58B	61B	51C	52C	59B	63A	66A	66A
	Average	29C	32B	27C	28C	31B	34A	34A	34A

(Continued)

TABLE G-6 (Continued)

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-7. AVERAGE DTPA-TEA EXTRACTABLE ZN CONCENTRATIONS OVER TIME AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Sampling times in weeks following sludge application							
		0	3	7	12	20	40	56	68
C	Mt/ha	ppm							
16	0	.93	1.10	.87	.84	1.05	1.5	1.6	1.4
	56	43	46	46	49	45	49	51	56
	112	79	83	90	99	99	95	96	102
	Average	41a*	43a	46a	49a	48a	53a	49a	53a
22 (Ambient)	0	1.05	1.10	.93	1.13	.96	1.2	1.4	1.5
	56	43	46	44	47	45	48	48	54
	112	83	81	90	89	92	96	90	101
	Average	43a	43a	45a	46a	46a	43a	46a	52a
27	0	.93	.97	.76	.85	1.00	1.3	1.4	1.5
	56	40	43	44	46	46	47	46	51
	112	89	81	89	93	96	89	93	98
	Average	43a	42a	45a	47a	48a	46a	47a	50a
35	0	.89	1.12	.99	1.25	1.30	1.2	1.5	1.8
	56	42	46	41	44	47	47	46	48
	112	85	79	85	89	88	86	87	92
	Average	43a	42a	42a	45a	45a	45a	45a	47a
Average	0	.95F	1.07F	.89F	1.02F	1.08F	1.3F	1.5F	1.6F
	56	42E	45E	44E	47E	46E	48E	48E	52E
	112	84CD	81D	88BD	92ABC	94AB	91ABC	91AB	99A
	Average	42D	42D	44C	47B	47B	47B	47B	51A

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TABLE G-7 (Continued)

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

TABLE G-8. AVERAGE DTPA-TEA EXTRACTABLE CD CONCENTRATIONS OVER TIME AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Sampling times in weeks following sludge application							
		0	3	7	12	20	40	56	68
C	Mt/ha	ppm							
16	0	.02	.03	.05	.05	.06	.05	.07	.05
	56	.32	.32	.29	.29	.30	.30	.32	.26
	112	.55	.55	.52	.48	.51	.49	.50	.45
	Average	.30a*	.30a	.29a	.27a	.29a	.31a	.29a	.25a
22 (Ambient)	0	.05	.03	.05	.05	.05	.06	.07	.05
	56	.23	.33	.29	.29	.30	.32	.31	.29
	112	.56	.55	.51	.43	.48	.48	.46	.45
	Average	.28a	.30a	.29a	.26a	.27a	.26a	.28a	.26a
27	0	.03	.03	.05	.05	.05	.06	.07	.05
	56	.35	.30	.30	.29	.29	.30	.34	.30
	112	.57	.53	.51	.46	.47	.45	.47	.44
	Average	.32a	.29a	.29a	.27a	.27a	.27a	.29a	.26a
35	0	.04	.03	.04	.05	.04	.05	.06	.05
	56	.32	.31	.29	.30	.31	.30	.31	.29
	112	.55	.53	.48	.43	.36	.44	.44	.42
	Average	.30a	.29a	.27a	.26a	.24a	.26a	.27a	.25a
Average	0	.03D	.03D	.05D	.05D	.05D	.06D	.07D	.05D
	56	.31C	.32C	.29C	.29C	.30C	.30C	.32C	.28C
	112	.56A	.54A	.51A	.45B	.45B	.46B	.47B	.44B
	Average	.30A	.30A	.28B	.26B	.27B	.27B	.29B	.26B

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TABLE G-8. (Continued)

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE G-9. AVERAGE DTPA-TEA EXTRACTABLE NI CONCENTRATIONS OVER TIME AS AFFECTED BY SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION

Soil temperature	Sludge rate	Sampling times in weeks following sludge application							
		0	3	7	12	20	40	56	68
C	Mt/ha	ppm							
16	0	.21	.47	.36	.30	.31	.18	.41	.47
	56	1.39	1.63	1.72	1.76	1.82	1.37	1.23	1.80
	112	2.31	2.25	3.27	3.50	3.74	2.85	2.52	2.96
	Average	1.30d*	1.45bcd	1.78ab	1.86a	1.96a	1.60abc	1.38cd	1.74a
22 (Ambient)	0	.21	.40	.44	.37	.30	.24	.36	.34
	56	1.03	1.58	1.59	1.69	1.54	1.73	1.46	1.72
	112	2.40	2.47	3.02	3.02	3.52	2.46	2.28	2.99
	Average	1.21d	1.48bcd	1.68abc	1.69abc	1.78ab	1.35cd	1.36cd	1.68a
27	0	.20	.42	.33	.45	.34	.22	.39	.34
	56	1.31	1.47	1.59	1.62	1.77	1.31	1.54	1.64
	112	2.63	2.24	3.15	3.17	3.26	2.31	2.42	2.83
	Average	1.38cd	1.38cd	1.69ab	1.75ab	1.79ab	1.28d	1.45bcd	1.60a
35	0	.20	.49	.33	.42	.37	.17	.43	.36
	56	1.37	1.56	1.69	1.62	1.78	1.28	1.50	1.63
	112	2.59	2.36	2.97	3.11	2.63	2.13	2.38	2.59
	Average	1.39cd	1.47bcd	1.67abc	1.72ab	1.60ab	1.19d	1.43bcd	1.53a
Average	0	.21F	.45F	.37F	.39F	.33F	.20F	.40F	.38F
	56	1.28E	1.56D	1.65D	1.67D	1.73D	1.42E	1.43E	1.70D
	112	2.48C	2.33C	3.11A	3.20A	3.28A	2.47C	2.40C	2.84B
	Average	1.32C	1.44C	1.70A	1.75A	1.78A	1.36C	1.41C	1.64B

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TABLE G-9. (Continued)

* Values within columns followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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(4-76)

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TABLE G-10. EFFECTS OF SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION ON THE CONCENTRATION OF SEVERAL HEAVY METALS IN SOIL SAMPLED ON 5-20-75. CONCENTRATIONS WERE DETERMINED BY EXTRACTING THE SOIL WITH .05N HCl AND .025N H_2SO_4

Soil temperature	Sludge rate	Zn	Cu	Cd	Ni	Pb
C	Mt/ha			ppm		
16	0	2c*	1a	.06a	.21a	.9a
	56	65b	39a	.50a	2.01a	7.1a
	112	137a	73a	.87a	3.84a	10.2a
	Average	68A	37A	.47A	2.01A	6.1A
22 (Ambient)	0	2c	1a	.05a	.31c	1.0a
	56	61b	39a	.48a	1.99b	7.4a
	112	133a	75a	.84a	3.79a	9.8a
	Average	65A	39A	.46A	2.03A	6.1A
27	0	2c	1a	.05a	.32c	1.1a
	56	60b	38a	.48a	1.93b	5.6a
	112	142a	71a	.78a	4.08a	8.8a
	Average	68A	37A	.44A	2.11A	5.1A
35	0	2c	1a	.05a	.36c	1.0a
	56	64b	42a	.49a	2.16b	7.4a
	112	142a	79a	.85a	3.85a	9.3a
	Average	69A	41A	.46A	2.12A	5.9A
Average	0	2C	1C	.05C	.30C	1.0C
	56	62B	38B	.49B	2.02B	6.9B
	112	138A	74A	.83A	3.88A	9.5A

* Values within each metal followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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TABLE G-11. EFFECTS OF SOIL TEMPERATURE AND SEWAGE SLUDGE APPLICATION ON THE CONCENTRATION OF SEVERAL HEAVY METALS IN SOIL SAMPLED ON 3-19-76. CONCENTRATIONS WERE DETERMINED BY EXTRACTING THE SOIL WITH .05N HCl AND .025N H_2SO_4

Soil temperature	Sludge rate	Zn	Cu	Cd	Ni	Pb
C	Mt/ha	- - - - - - - - - -		ppm	- - - - - - - - - -	
16	0	2c*	1a	.07a	0.28a	0.49a
	56	63b	41a	.44a	1.96a	2.70a
	112	127a	82a	.76a	3.52a	4.20a
	Average	64A	41A	.42A	1.92A	2.47A
22 (Ambient)	0	2c	5a	.07a	0.28a	0.57a
	56	62b	42a	.45a	2.25a	2.36a
	112	119a	79a	.74a	3.43a	4.09a
	Average	61B	42A	.42A	1.99A	2.34A
27	0	2c	1a	.07a	0.22a	0.53a
	56	61b	41a	.34a	1.88a	.39a
	112	125a	82a	.76a	3.21a	3.38a
	Average	63A	42A	.39A	1.77A	2.10A
35	0	2c	1a	.07a	0.28a	0.51a
	56	59b	39a	.44a	1.89a	2.05a
	112	114a	77a	.71a	2.83a	3.64a
	Average	58C	39A	.40A	1.67A	2.07A
Average	0	2C	2C	.07C	0.27C	0.53C
	56	62B	41B	.42B	1.99B	2.38B
	112	121A	80A	.74A	3.24A	3.83A

* Values within each metal followed by the same letter are not statistically different at the 5% level of significance as determined by Duncan's Multiple Range Test. Capital letters denote main effects.

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